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ANGLO-AUSTRALIAN LONG RANGE WEAPON PROJECT

By L. J. Carter, A.C.I.S.

Introduction

The proposed Australian rocket range was surveyed in the winter of 1946 by a joint United Kingdom-Australian party, led by Lt.-Gen. J. F. Evetts, a representative of the Ministry of Supply.

For some time it had been known that a suitable range must be found for the future development of guided missiles, and it was obvious that some vast desolate track could be the only solution as far as actual experimentation was concerned.

There were a number of such places, for example, in Canada, but here firing trials would have to take place over deep snow in winter, and subsequent recovery of the missiles would be difficult, if not impossible.

The advantages offered by the Australian site were good visibility throughout the year, and opportunities for observing and recovering the missiles. There were disadvantages, of course, *i.e.* lack of water, poor communications, and the absence of other essential facilities in the uninhabited desert, but it was considered that the balance of advantage definitely lay with the Australian site.

Accordingly, the responsibility for setting up an organisation to conduct all aspects of long-range weapon research was given to the Australian Department of Supply and Development. In 1947 a party of engineers and scientists arrived from the United Kingdom under the leadership of Lt.-Gen. Evetts, and the Long-Range Weapons Organisation was established as a joint United Kingdom-Australian enterprise.

Launching Site

The potential range in Australia lay almost entirely across a huge region of about 1 million square miles, with an average rainfall of about 6 in., and never more than 10 in., though the infrequent downpours flood the plains. Hardy saltbush and bluebush, sparse and only a foot high, forms the only vegetation, though this provides sustenance enough for sheep in the vicinity of the range-head. (Wilgena, the largest sheep station, runs to an area of nearly 2 *million* acres.)

The advance headquarters are 120 miles from the South Australian gulf settlement of Port Augusta, and within a closed security zone of 3,000 square miles is the launching site for guided missiles fired over the range.

The rocket range corridor lies across empty wilderness to the shores of the Indian Ocean 1,200 miles north-west, but it could ultimately be extended over the sea to give a total length of 2,700 miles, Christmas Island in the Indian Ocean then marking the extreme end of the range.

Woomera is the name given to the rocket base, aptly chosen because it is also the aboriginal name for the launching device which speeds a spear far to its target.

Map showing the site of the rocket range.

Facilities and Construction

During the war, the largest war plant in Australia was built on the Salisbury Plains, 14 miles north of Adelaide, and this has now been taken over entirely for rocket research. It was constructed at a cost of 7 million pounds, and consists of about 1,500 buildings extending over 5,000 acres. The large factory buildings are now being filled with equipment for the rocket range as the project gets under way.

The base itself is in "gibber" country (an aboriginal name for the myriads of black and reddish stones which litter the desert floor and blaze in the sunshine)—the area reaching far to the north and west to form what has so often been called the "dead heart" of the country.

At present about 1,200 civilians and servicemen are engaged on construction work and living in tents forming several little settlements dispersed over 5 or

General view of the hutments in Salisbury base.

6 square miles. Water is piped from 2 lakes within 25 miles, and tends to be saline, but the rangehead is to be linked with the pipeline at Port Augusta, which carries water from the Murray River, 120 miles away.

In due course a model village will be constructed, grouped round a community centre, and having churches, schools, a hospital, golf course, etc.

Workers will be able to live on the site with their families in surroundings designed to alleviate the rigours and tedium of desert life; their homes will be conditioned to the temperature, which rises to 120° in the daytime, and falls to 35° at night.

Work is progressing rapidly in blasting and crushing rock for building a network of roads, buildings, and laboratories. Three landing strips have also been built, one 2½ miles long, and the other two, 2 miles long. Hangars are also being built for aircraft and storage purposes. These will be in regular use to shuttle personnel and staff between the rear establishments and base head.

A 6 miles railway line has been laid to connect the base with the transcontinental line at the desert station of Pimba.

Work is also progressing beyond the base and on the actual launching site. A chain of observation posts has been constructed along the line of fire, equipped with electronic and optical instruments to enable the behaviour of missiles in flight to be studied.

Personnel

The organisation and layout envisages an eventual expansion into a huge permanent base, with scientists, technicians, representatives of the services, and operative staff working together.

To build up a nucleus of rocket staff, young Australian engineers are being recruited and sent to England for two years' training; when they return they will join the teams at Salisbury.

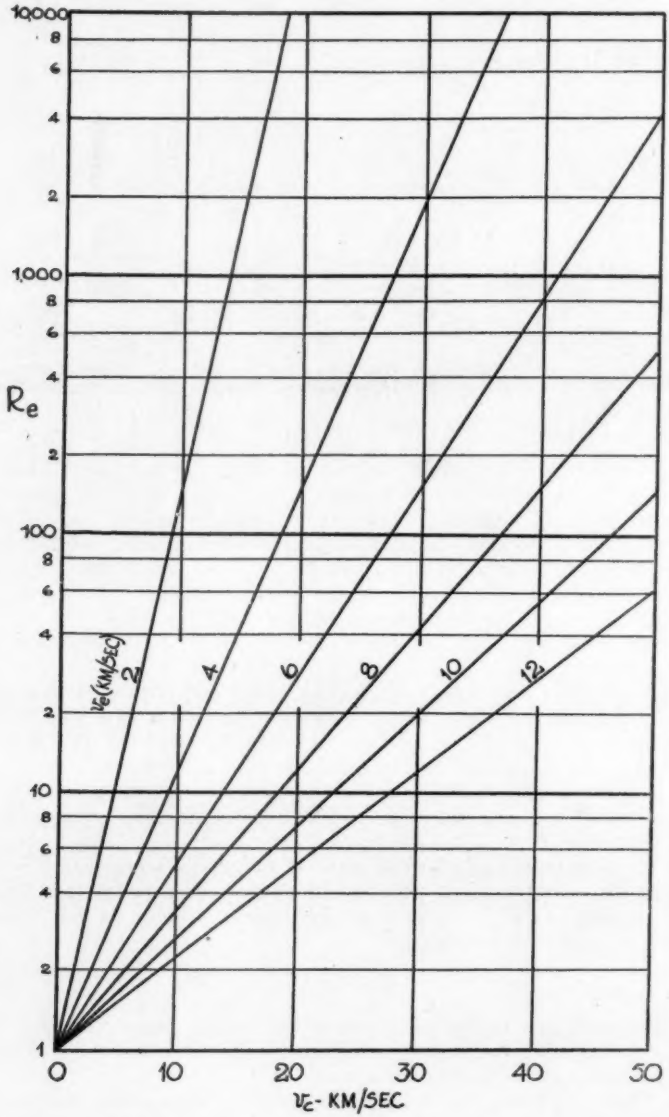

FIG. 1. Variation of effective mass ratio (R_e) requirement with characteristic velocity (v_c) and effective exhaust velocity (v_e).

Fundamental research on guided missiles will still be carried on in Britain. Little or no information is available about actual research being carried on at present, probably because the centre is still in its "teething" stage, but it is known that tests have already commenced, including the firing of missiles.

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THE CALCULATION OF TAKE-OFF MASS

By A. V. Cleaver, A.R.Ae.S.

I. Introduction

This paper is intended to be read in conjunction with a previous one[1]; the definitions of the terms, symbols and equations here employed are the same as in the earlier article, to which reference should be made where necessary, although some of the relevant relations are repeated for convenience.

Figure 1 shows the effective mass ratio (R_e) required for a given characteristic velocity (v_c), for various values of the effective exhaust velocity (v_e). It is calculated from equation 1 (see also 5) of reference 1, viz.:—

$$v_c = v_e \log_e R_e.$$

Figures 2 and 3 show the effective mass ratios obtainable by the use of the step principle, in terms of the number of steps employed (n) and the payload ratio (λ). Fig. 2 is drawn for a value of the structural factor (ϵ) = 0·20, while for Fig. 3 this parameter has been assumed = 0·10. The former value should certainly be possible for future large rockets, at least of the orthodox chemical type, although it is quite appreciably more favourable than anything achieved to date. The latter value is considered decidedly optimistic. With these assumptions, all the curves were calculated from equation 11 of reference 1, viz.:—

$$R_e = [\epsilon (1 - \lambda) + \lambda]^{-n}.$$

The payload ratio (λ) and the structural factor (ϵ) have been assumed the same for all steps—an optimum, but not essential, condition; also, the convention adopted by various GALCIT workers, with regard to the definition of ϵ for the final (payload-carrying) step, has been used. These points are discussed further in reference 1.

Finally, Figure 4 gives the resultant over-all payload mass ratio (G), in terms of n and λ. It was obtained from equation 13 of reference 1, viz.:—

$$G = \lambda^{-n}.$$

This again assumes constant λ for all steps.

II. Example Calculation

Figures 1 to 4 inclusive may be used to estimate the take-off mass requirement for various interplanetary missions. A number of examples are worked out below, and readers may care to investigate others for themselves.

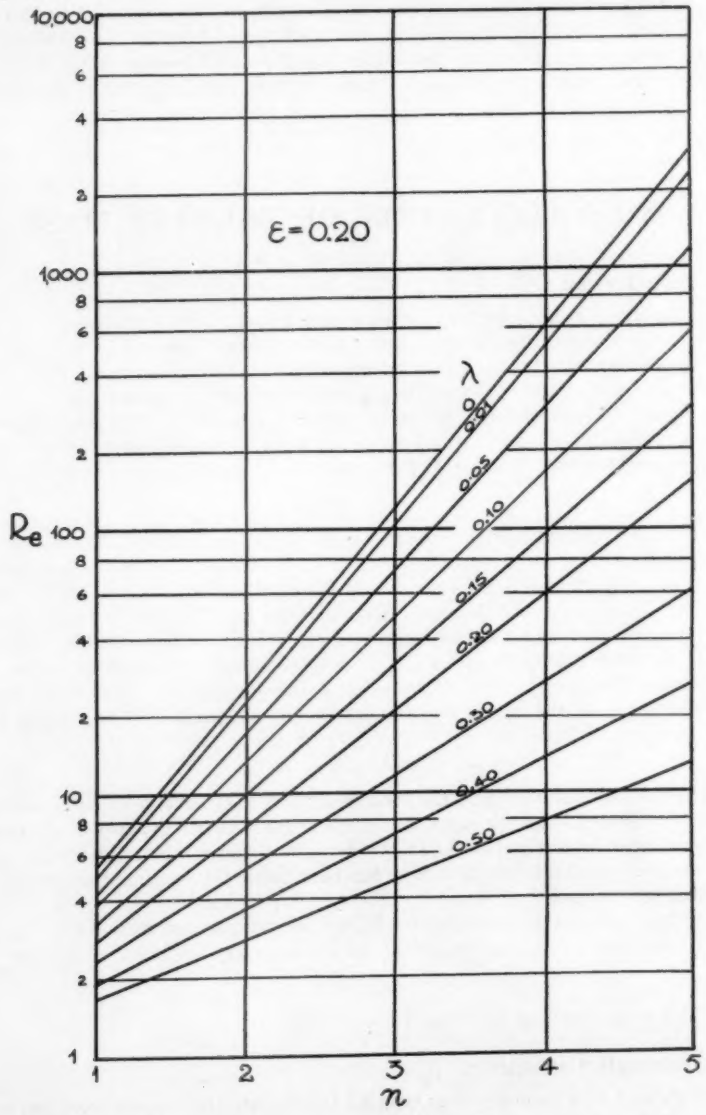

FIG. 2. Variation of effective mass ratio (R_e) with number of steps (n) and payload ratio (λ). $\epsilon = 0{\cdot}20$.

The case chosen for illustration here is that of an "Earth-Moon-return to Earth" voyage, with a landing at the lunar destination. For such a mission, the characteristic velocity required[2,3] is of the order of 30 km./sec., assuming that only a relatively small use of atmosphere braking can safely be employed during the final approach and landing manœuvre back to Earth.

(*a*) *Chemical Rocket.*

$v_e = 4{\cdot}0$ km./sec. (This is about the maximum which can ever be hoped for from chemical propellants.[2])

$\epsilon = 0{\cdot}20$ (a reasonable value).

$n = 5$ (a greater number of steps than five would imply a very complicated design, hence this is the largest number considered in this paper. On the other hand, for given values of v_e and ϵ, it would, of course, follow that a smaller number of steps would imply a lower λ value. In some cases, the required characteristic velocity would be unobtainable with $n < 5$, whatever the value of $\lambda : v_c \not> -nv_e \log_e \epsilon$).

From Figure 1, for $v_c = 30$ km./sec. and $v_e = 4$ km./sec., we have

$$R_e = 1{,}810.$$

From Figure 2, for $n = 5$, $\epsilon = 0{\cdot}20$, and $R_e = 1{,}810$, we have

$$\lambda = 0{\cdot}0288.$$

Finally, from Figure 4, for $n = 5$ and $\lambda = 0{\cdot}0288$, we have

$$G \gg 1{,}000{,}000.$$

Actually, for these conditions G would be equal to 50,500,000. Clearly, this is an utterly impracticable result; it means that for every single tonne of payload carried on the journey, the take-off mass requirement would be over 50,000,000 tonnes! Such an answer is not only beyond the limits for which the curves are drawn, but also beyond anything which could ever be regarded as economically acceptable, even if the practical engineering difficulties of providing adequate take-off thrust could be surmounted.

(*b*) *Chemical Rocket with improved structure.*

$v_e = 4{\cdot}0$ km./sec. and $n = 5$, as before.

$\epsilon = 0{\cdot}10$. (Certainly something better than the 0·20 of (*a*) might be possible, but this value of 0·10 may be regarded as a very optimistic limiting case.)

Using the same procedure as before, but with Figure 3 this time instead of Figure 2, we have

$R_e = 1{,}810$ still, because v_c and v_e are unchanged.

$\lambda = 0{\cdot}137.$

$G = 20{,}700.$

This is a much less staggering result than the previous one, but still unacceptable. It is, of course, as a consequence of such calculations as these that the general inference has been drawn that true interplanetary flight must await the advent of nuclear power for propulsion; the exhaust velocities obtainable from chemical propellants simply are inadequate. (The only possible reservation to this view concerns the use of "orbital stage techniques," about which more will be said later.)

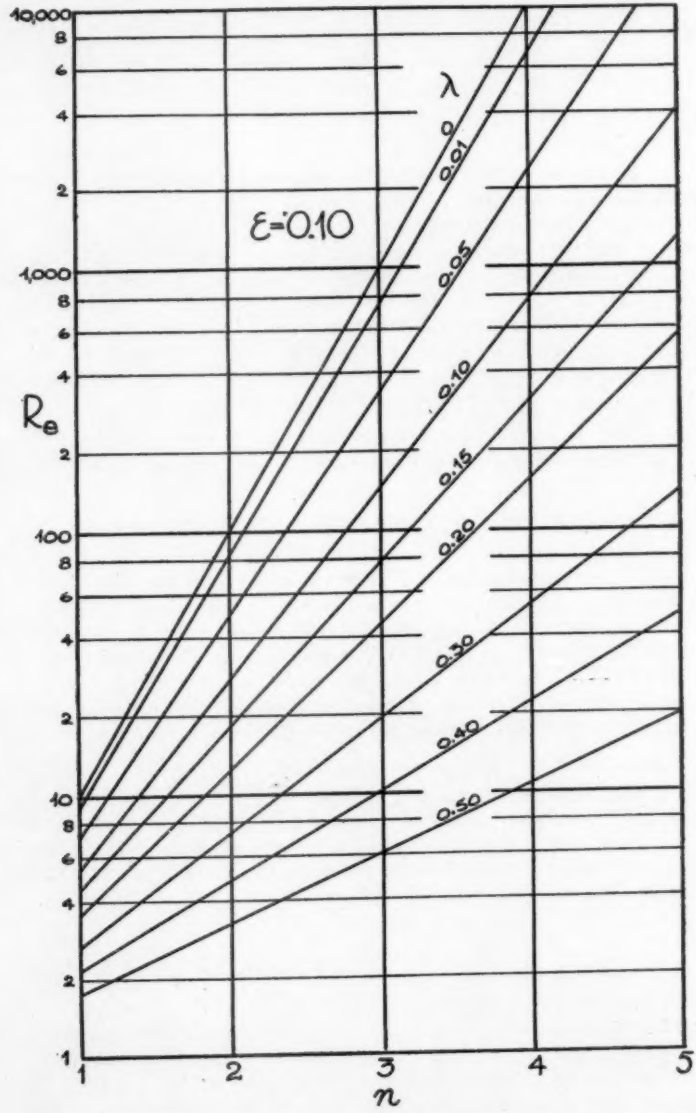

FIG. 3. Variation of effective mass ratio (R_e) with number of steps (n) and payload ratio (λ). $\epsilon = 0{\cdot}10$.

(*c*) *Atomic Rocket.*

$v_e = 8{\cdot}0$ km./sec. (Such an exhaust velocity might quite conservatively be hoped for from a future power unit of the type employing nuclear energy to accelerate a jet composed of some gas of low molecular weight.[2])

$\epsilon = 0{\cdot}20$. (In view of the shielding requirements of a nuclear power unit, it is perhaps unlikely that this figure could be bettered.)

For the same 30 km./sec. characteristic velocity $n = 5$, we have

$$R_e = 42{\cdot}5.$$
$$\lambda = 0{\cdot}341.$$
$$G = 217.$$

This result is beginning to look much more reasonable; it will be noted that the R_e value is equal to the square root of that obtained in (*a*), the exhaust velocity having been doubled.

(*d*) *Chemical Rocket, with reduced characteristic velocity requirement.* It is conceivable that the velocity needed for the lunar trip, with landing, might be reduced to something approaching only 20 km./sec., *providing*—

(i) High take-off accelerations could be employed, with an optimum ascent path (what Oberth called the "synergic curve").

(ii) Losses due to air drag at take-off, correction of course errors, etc., could be kept to an absolute minimum.

(iii) Above all—that air braking could be used to provide nearly all the retardation necessary for the final landing back on Earth.

For the mainly illustrative purposes of this article, therefore, we shall assume

$v_e = 20$ km./sec. (Probably very optimistic.)
and $v_e = 4$ km./sec. as for (*a*).
$\epsilon = 0{\cdot}20$,, ,, (*a*).
$n = 5$,, ,, (*a*).

These assumptions give the results

$$R_e = 148$$
$$\lambda = 0{\cdot}210$$
$$G = 2{,}450$$

which represent a striking improvement on case (*a*).

(*e*) *Atomic Rocket, with reduced characteristic velocity requirement.*

$v_e = 20$ km./sec., as for (*d*).
$v_e = 8$ km./sec. ,, ,, (*c*).
$\epsilon = 0{\cdot}20$,, ,, (*c*).
$n = 5.$,, ,, (*c*).

This case, in other words, is directly comparable with (*d*) and appropriate use of the Figures gives

$R_e = 12{\cdot}2$ (Again, $= \sqrt{148}$, because v_e has been doubled.)
$\lambda = 0{\cdot}508$
$G = 29{\cdot}6$

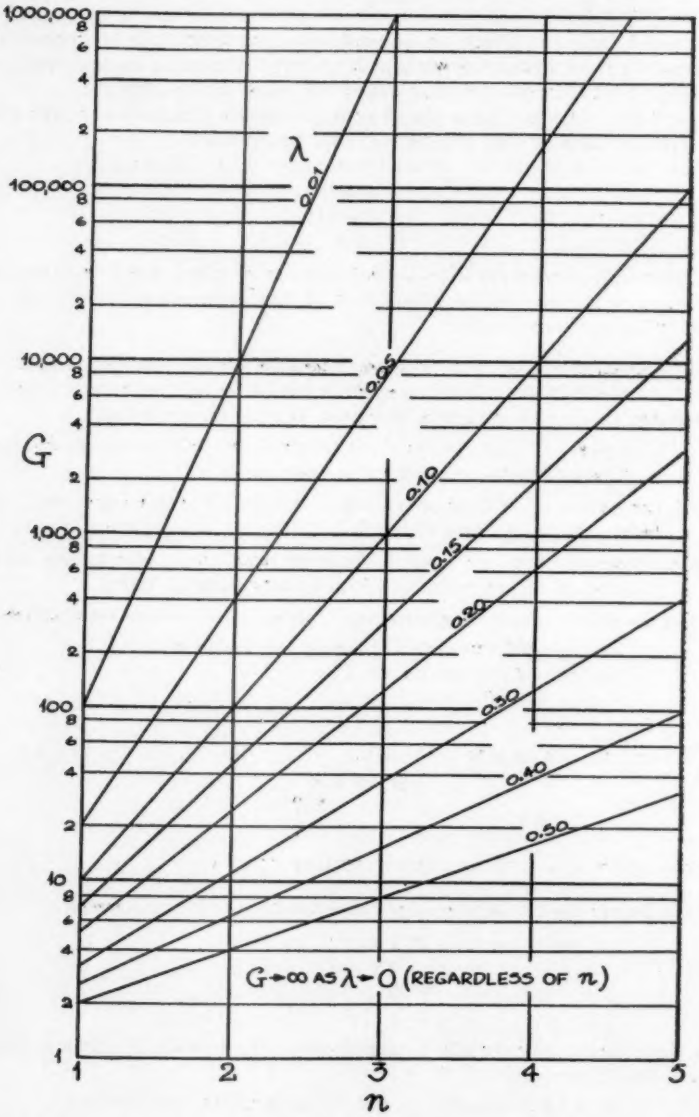

FIG. 4. Variation of overall payload mass ratio (G) with number of steps (n) and payload ratio (λ).

It may be mentioned that these assumptions would probably result in an impracticable case for a new reason; the individual step masses would be so low (unless the payload itself were very large) that it is perhaps unlikely that nuclear power units could be made, with shielding, in such small sizes. Should this much reduced characteristic velocity prove reasonable, therefore, in practice any atomic rocket built to satisfy it would probably use a smaller number of steps than the five assumed here.

III. Summary

The most interesting of the foregoing numerical results have been collected for convenience into a table, which also shows some further information obtainable from the data listed in reference 1.

TABLE

ROCKETS WITH 5 STEPS. "PAYLOAD" = 10 TONNES

Case	(a)	(b)	(c)	(d)	(e)
v_e (km./sec.)	30	30	30	20	20
v_s (km./sec.)	4	4	8	4	8
ϵ	0·20	0·10	0·20	0·20	0·20
λ	0·0288	0·137	0·341	0·210	0·508
Take-off mass, M_o (tonnes)	505,000,000	207,000	2,170	24,500	296
Mass of final step (tonnes)—M_s, full	347	73·0	29·3	47·6	19·7
Mass of final step (tonnes)—m_s, empty	77·4	16·3	13·9	17·5	11·9
Effective Mass Ratio, R_e	1,810	1,810	42·5	148	12·2
True Mass Ratio, R_o	6,520,000	12,700	156	1,400	24·8

For example, the total take-off mass has been included, on the assumption that the "payload" of the final step will be 10 tonnes. This figure is considered reasonable, on the basis of the λ and ϵ definitions adopted here, which would suggest that the "payload" should be regarded as including, not only the crew, their air, food, drink and instruments, but also the pressure cabin and ancillary equipment required to house them and provide for their comfort. Such items could not legitimately be regarded as "structure," in the sense that the final step is assumed to have the same ϵ value as the lower steps, for which they are absent.

With payload m_l, the total take-off mass is given by

$$M_o = G\, m_l.$$

The mass of the final step, when full of propellants, is

$$M_s = \frac{m_l}{\lambda},$$

and when empty

$$m_s = \epsilon\,(M_s - m_l) + m_l.$$

(See equations 7, 8, etc., of reference 1, which also provide the means of calculating the individual masses, full and empty, of the other steps.)

For comparison with the *effective* mass ratio (R_e), the *true* mass ratio (R_o) is given by

$$R_o = \frac{M_o}{m_s}. \quad \text{(Equation 2 of reference 1.)}$$

It is, of course, very much greater in magnitude.

The data of the above table make it possible to draw certain obvious, but very important and fundamental conclusions about space-travel; these may be summarised as follows:—

(1) Even with very large improvements on present motor performances and structural design, it is going to be difficult to avoid the use of very large and heavy vehicles in relation to their carried payload. This may be thought of as a continuation of the trend already exemplified by aircraft, as compared with surface transport, especially as regards the fuel (propellant) expenditure per mission.

(2) Due to the exponential nature of the fundamental relation involved, the overall picture is most critically affected by any variations in motor performance or structural design quality. Relatively small increases in the exhaust velocity (v_e), or reductions in the structural factor (ϵ), are responsible for immense improvements in the situation.

(3) For the same reason as quoted in conclusion (2), the practicability of interplanetary flight is very much influenced by the magnitude of the characteristic velocity demanded. This places a premium upon any attempts to reduce that demand—for example, by the extensive use of air-braking for an Earth landing—down to the absolute minimum consistent with safety and reasonable reserves. In the past, however, there have been a number of studies published which certainly did not satisfy the latter conditions; one must not base one's hopes on a too-marginal flight plan.

IV. Orbital Techniques

By far the most promising line of development for reducing characteristic velocity requirements lies in the direction of what Gatland[4] has called "orbital techniques." As far as the present writer knows, these were first proposed by Ing. Guido von Pirquet (now an Honorary Fellow of the B.I.S.) some 20 years ago. More recent times have brought a realisation that, even with the availability of nuclear power, some such solution is still, in all probability, going to provide the key which will unlock the solar system to human exploration.

Briefly, von Pirquet's idea was that artificial satellites, or space-stations, should first be set circling the Earth in stable orbits. Rockets would then be used to ferry propellants out to the stations in a series of successive trips, so that a store would gradually be built up and eventually would be used to refuel a final rocket. After climbing up to a station and there refuelling, this last

rocket would be capable of resuming its journey to the Moon or to some other planet. Of course, the same procedure could be followed repeatedly, the same rockets and space-station being used for a number of expeditions. The total overall fuel consumption would not be reduced by the use of such techniques (indeed, it would probably be very materially increased), but the size of the individual rockets employed would be much smaller than in any direct scheme. Granted the practicability of making the necessary rendezvous in space (which appears quite feasible when one considers that only relative velocities are involved), then the proposal reduces the whole project of interplanetary flight to a much more reasonable level of engineering achievement.

Von Pirquet and the other pre-war German pioneers propounded the scheme in very much the terms outlined above, but, of course, many variations on the theme are possible, and have been discussed,[4,5,6,7] For example, the station in space need not necessarily be used at all; the tender rockets may come alongside the spaceship itself and transfer their propellant payload directly into its tanks.

An Earth-Moon expedition with a lunar landing, employing such an orbital technique, would not need to use rockets with a greater characteristic velocity than 15 km./sec. at any stage of the proceeding. Even with the 4 km./sec. exhaust velocity likely to be available eventually from the best chemical propellants, this would involve the need for an effective mass ratio of only 42·5. Since both the characteristic and exhaust velocities are halved, this happens to give the same results as case (*c*) of those previously considered, assuming that the number of steps employed were still five, and $\epsilon = 0{\cdot}20$.

If an atomic drive with $v_e = 8$ km./sec. were available, then R_e would need to be no more than 6·52 ($\epsilon = 0{\cdot}20$ again). With only two steps, this would then correspond to $\lambda = 0{\cdot}240$ and $G = 17{\cdot}4$ (i.e., 174 tonnes total take-off mass for 10 tonnes "payload"). It is also quite possible that the characteristic velocity could be reduced below 15 km./sec., providing that aerodynamic means could be largely employed for landing the orbital "ferry" rockets back on Earth.

In practice, considerations of radioactivity in the exhaust would probably lead to the employment of chemical take-off and landing steps, so that the figures quoted (based on a constant exhaust velocity for all steps) are an over-simplification; similarly, there would in all likelihood be a difference in ϵ between the atomic and chemical steps. It is nevertheless hoped that this discussion may have served to throw some light on the fundamental problems of space-flight, by placing certain matters in their proper perspective. In this last section, it is the writer's belief (shared with other members of the B.I.S. Technical Committee) that the most promising future line of development for astronautics has been touched upon.

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PSYCHOLOGICAL PROBLEMS OF SPACE-FLIGHT*

By E. T. O. Slater, M.A., M.D., F.R.C.P.

I feel that I am appearing here under somewhat false pretences, as I do not believe that purely psychological problems offer any special difficulties in the programme which lies before mankind and is the peculiar interest of this Society. I may, perhaps, make my standpoint clearer if I briefly discuss the nature of psychological stress and its effect on the human organism.

Psychiatrists received an object-lesson on the modes of nervous breakdown under strain during the last war. It was so informative because the situation was an almost experimental one, and the strains imposed were largely standardised. By far the most important of them can be classified under the heading of anxiety. For battle-troops there were the anxieties of facing the risks of death in engagements with the enemy. In battle itself, the body and the mind are tuned up to do what has to be done and are completely engaged; in the heat of battle, therefore, anxiety is comparatively little felt. Its main effects are shown in causing apprehension in the quiet period of waiting for orders before battle. Similar strains were felt by air-crews; but in the case of the crews of bombers, the anxiety and nervous tension might be felt during many hours of flight over enemy territory, while the engagement itself, with enemy fighters or ack-ack fire, was confined to a narrow interval of time. Again, the strain of fighting in the jungles of the Far Eastern theatre, with the soldier never knowing behind which bush the enemy might lie concealed, was of an essentially similar nature.

In all these cases activity was fairly easily tolerated, however dangerous, provided it was energetic enough; what was difficult to bear was prolonged inactivity and the passive waiting for risks which were yet to appear. The nervous systems of participants were put through a phasic series of strains, each phase consisting of a long period of mounting tension and apprehension, a short period in which this tension was released in action, during which time the main risks were met, and, danger passed, a period of recovery.

The reactions of human beings to any form of test situation are highly variable. A rather small minority of men actually developed symptoms at the mere idea of the strains I have described, and were accordingly found medically unfit to be subjected to them. Another rather small minority withstood the first or second phase and then could not go on. The great majority, finding that they survived the first few tests, were then enabled to continue until more insidious factors made their effect felt. If strains were severe, and rest periods were short, the time would come when apprehension persisted during and after the relief stage, and gradually accumulated. This could to some extent be mitigated or postponed by allowing a very thorough release of tension and a rest which, if short, was complete. It was no wantonness on the part of airmen that caused them to seek, after an engagement, an alcoholic "binge." Nevertheless, the general incapacity of human beings to take more than a certain amount of strain, led the authorities in the R.A.F. to restrict tours of duty.

* *This is the first of three papers under the title of "A Symposium of Medical Problems Associated with Space-Flight" read to the Society in London on November 19, 1949.*

Another phenomenon which is perhaps worth mentioning here is that it was found that anxiety even of a persistent kind was better tolerated in circumstances in which it was appropriate than in conditions when it was not. In the Navy, for instance, men were naturally anxious when sailing through mine-fields or within the reach of enemy submarines, and became to some extent accustomed to the lasting state of tension. When, however, the same feeling persisted in circumstances of safety ashore, it was found much more oppressive.

Of rather less frequency and importance than the results of anxiety and apprehension were the hysterical breakdowns. These made up by far the larger part of the breakdowns which occurred during battle or in the emergency situation. Usually after some sudden shock, such as a near shell explosion, or seeing his friend killed at his side, a man would suffer a sudden disruption of nervous integration. He would perhaps start running wildly, even in the face of the enemy; or perhaps fall to the ground and on trying to pick himself up find one or more of his limbs were paralysed. Subsequently, doctors would often find a blanking out of the memory for the period which immediately preceded and followed the collapse. The majority of the men who broke down in this way suffered a good deal beforehand, and the final breakdown can be likened to the sudden snapping which may terminate a more gradual giving way under pressure. In a few cases, however, the patient had remained apparently well until the final acute episode.

One other type of neurotic reaction should be mentioned, the depression, disgruntlement and irritability which attacked many men who had to put up with prolonged periods of inactivity, discomfort and worry. These symptoms were a particular headache to commanding officers, and were thought of as a form of bad morale. Bad morale was, of course, a much greater danger in defeated troops than in those who had enjoyed recent successes.

Now if we relate the principles I have outlined to the psychological situation in the cabin of a spaceship, we can see their applicability. The crew will necessarily be under a considerable degree of tension, and have to face many anxieties and sources of danger, some of which are unknown. Problems of boredom are not likely to arise on comparatively short journeys of a few hundred thousand miles. But if a journey is being undertaken to Mars or further, there may be months to be spent in an extremely confined space, and with perhaps very little to be done. Sudden emergencies may well interrupt these prolonged spells of inactivity, providing adequate stimulus for an acute hysteria in one of the crew. It will therefore be essential to pick men for the crew who have shown no previous sign of instability, and who have past experience of a type to assure their reliability. It is essential to emphasise this point: purely experimental and artificial psychological and psychiatric tests by themselves are not enough.

This all sounds, perhaps, rather formidable; but it is not as bad as it seems. We can diminish the psychological risks involved in space-flight to an almost negligible level, by a judicious choice of personnel. Just as a small proportion of humanity are so unstable or anxious that they break under a minimal strain, so there is a small proportion which will stand almost any foreseeable strain of a purely psychological kind. We can think of the men who have explored the

Arctic and Antarctic, have wintered many months in the ice-huts, those who have undertaken forlorn adventure in war under a virtual certainty of death, and have yet maintained their sense and sanity. If we choose our crew from such men we should have an ample margin of safety. I cannot see any reason to fear that the psychological strains and the risks of space-flight will be greater than humanity has successfully met in the past on many occasions. I am, however, speaking only of psychological strain, and this brings me to another part of my subject.

Nervous stability is closely dependent on the physiological state of the body. Previously stable men broke down during the war if their bodily health was reduced, as it might be by insufficiency of sleep or diet or by prolonged physical exertion. Shipwrecked mariners, for instance, were sometimes subjected to such physical hardships and privations that the mental state of every member of the boat's company suffered. It is incumbent on us, therefore, to consider carefully what are the physiological strains which are involved in space-flight. When I enter on this field, I am stepping outside my own territory, and am not speaking as an expert. Nevertheless, I shall put some ideas before you, though in tentative fashion. While I know of no absolutely fixed upper level of psychological strain, above which no human being can go, physiological limits are narrowly fixed. Furthermore, limits of physiological stress which may be safely borne for a few hours can be intolerable if imposed for a period of weeks. Breakdown, when it occurs after such long periods of subjection to a stress which barely exceeds tolerable limits, is, indeed, very likely to show itself in a psychological form. This merely means that the nervous system is the most delicately regulated organ of the body. In essence, the problem is still a physiological one.

It will be absolutely essential for the engineers who design a manned spaceship to give special attention to, and to have expert advice on, human requirements in such obvious matters as air, food and water supply, and control of temperature. To take the last, the machinery supplied for heating and refrigeration should be such that the temperature maintained in the cabin is always not only tolerable, but comfortable. Large margins should be allowed to cope with an excess of temperature flow in either direction. Similar considerations apply to oxygen supply, tension of water vapour, the removal of carbon dioxide, and of the odorous products of perspiration, etc. I do not think I need go into these things any further, as I do not see any fundamental cause of difficulty.

The one and only factor of physiological stress which, as far as I can see is entirely unavoidable, is the force of gravitation. At the start of the flight, the acceleration of the ship will perhaps treble the normal value of g.; in the state of free fall, which I suppose will extend over the major part of the journey, the value of g. will be zero. Let us take the latter state of affairs first. Direct use of g. is made by very few physiological processes. The heart pumps the blood around, we swallow our food and drink, by forces which are independent of gravitation. Cellular activity depends on chemical action at surface membranes, osmosis, diffusion, etc., that is physical, chemical and electrical processes which are independent of g. The one part of the body which is intimately concerned with gravitation is the vestibular part of the inner ear, which supplies

us with information about our movements and our position in space. Now Dr. A. E. Slater is going to deal with this in a few minutes, so I will not trespass on his subject. I will, however, say that it would seem to me most desirable for the comfort of the crew, to provide a substitute for gravitation, when that is zero, by rotational spin.

Let us turn to the problems raised by the ship's initial acceleration. The effect of multiplying the gravitational field by a factor of 3 or more will be to treble the weight of all the body tissues. This is, of course, true whatever the position adopted, whether standing, sitting or lying. The crucial danger is encountered in the action of the heart. Even if the man lies flat on his back, the weight of the blood which has to be pushed into the arterial system and returned through the veins is multiplied—and the heart is no stronger. *X*-ray photographs of animals subjected to acceleration show a diminution of the heart shadow to the point where it almost empties of blood. If the blood is not moving, the tissues are deprived of oxygen and fuel and must suffer. Of course, the first organ to fail is the brain. I imagine that no one in the audience to-night but has heard of, perhaps even experienced, the blacking-out which overcomes the airmen during a rapid change in velocity. In the past this has been chiefly observed in turning movements, e.g. coming out of a dive. It is now, I believe, making itself felt in simple acceleration along a straight path, as in the rapidly accelerating jet-propelled aircraft. It is very likely to occur if the value of g. is multiplied by 3 or more.

We shall probably know a great deal more than we do at present about these gravitational effects, when the time comes to launch a manned spaceship. Medical officers of the R.A.F. are already in a position to supply information that I could not, about the effects, both momentary and lasting, on human physiology. I believe I am right in saying that pilots who have been through a number of black-outs begin to suffer mentally. The type of ill-effect produced resembles that seen after a head-injury, or in an epileptic patient who has had many fits. That is to say there are changes in temperament and personality of a kind which we associate with molecular, but widespread physical damage to the brain. In the pilot they are caused by the repeated attacks of cerebral anaemia.

It is, therefore, practically certain that the limiting factor in deciding with what speed escape velocity can be attained will be this physiological one. If the crew are to survive intact, acceleration would have to be much more gentle than in the case of an unmanned spaceship, and the expenditure of fuel correspondingly more extravagant. If some sort of compromise has to be reached between the demands of physiology and the total fuel-load that can be allowed to the spaceship, it may be that the number of tours which can be allowed to any one man will have to be limited, and that there will be a high rate of invalidism.

Let us now give fancy a stronger wing, and suppose that a manned spaceship makes a landing, let us say on Mars, where there are forms of life. Unless the crew find intelligent beings, there are no psychological problems of any moment I can think of. I have heard it suggested that there might be serious biological dangers in the meeting for the first time of two forms of life without previous

acquaintance. You will remember that in Wells's story of a Martian invasion of the Earth, the invaders were destroyed by falling victims to saprophytic organisms, the ordinary germs of decay which exist in countless myriads in every breath of our air and every drop of water on the Earth, which they were unable to resist. Would not man himself have to face a similar danger if he intruded into another world? I do not think so. The human organism is supplied with general and specific chemical weapons of defence. Some of our chemical immunities have to be acquired by the actual experience of disease. The human body also has very capable defenders in the white cells which circulate in the blood and destroy any germs which penetrate so far. The parasitic organisms which can get through the body's defences are few and through the course of ages have become specifically adapted to do so. It is to me unthinkable that, in another world, there might be organisms which would by chance be possessed of an immunity to human defence mechanisms. In other words, we are ourselves so well defended that we can only be attacked by parasites which have adapted themselves specifically to overcoming our defences; and we should be quite immune to organisms which have not become so adapted. This, of course, is no reason for thinking that human beings in a strange world might not find the naturally occurring foodstuffs of that world poisonous. Poisoning and disease are quite different problems.

The final question remains unanswered. What can we expect to happen if exploring man runs into another intelligent race? Will he be given a breathing space in which he can make some attempt at communication, or will he at once encounter direct and aggressive hostility? To attempt to answer this is to descend into almost pure speculation. Such relevant observations as we have, however, are reassuring. When man has penetrated into a virgin country, it has usually been found that the birds and beasts are astonishingly tame and unafraid. They have, in fact, become adapted to their enemies, and do not usually feel hostile to other creatures which they do not recognise as such and are merely strange and unknown. Even primitive man, living in tribes which are at war with their neighbours, meets such a strange newcomer as a white man without overt hostility. If Martians were to land on our own world, we would at least give them a chance to disclose friendly intentions. Although we can have no knowledge of the psychological make-up of an intelligent Martian, it is rather more probable than not that he will adopt an attitude towards the extramundane visitor which would in this respect resemble our own.

THE BALANCING MECHANISM OF THE INNER EAR*

By A. E. Slater, M.A., M.R.C.S., L.R.C.P.

One of the problems of space flight is the impossibility of knowing beforehand how the occupants of a spaceship will react to the apparent absence of gravitational pull. There is no way on Earth of submitting anyone to this condition for more than a few seconds at a time. Even a parachute-jumper, making a delayed drop, feels the sensation of gravity returning to him by degrees from

* *The second paper included in the Society's "Symposium of Medical Problems Associated with Space-Flight."*

the very moment of his jump, as the air resistance builds up and causes his rate of acceleration to slow down.

However, if we cannot find the complete answer to our question, we can go some way towards solving it by studying the organs in the inner ear which have the special function of telling us which way gravity is pulling.

What is popularly known as the ear is regarded by the anatomists as merely a part of the outer ear, the other part being the tube which leads from it inwards as far as the ear-drum. Beyond the drum is a small cavity called the middle ear, which is filled with air; and beyond that again is the inner ear, which consists of a complicated group of connecting passages, filled with fluid, and appropriately called the labyrinth.

One of these passages has a spiral shape like a shell, and contains the organ of hearing, known as the cochlea. The other passages constitute the balancing organs, and it is important to realise that these organs register *accelerations*, that is, rates of change of motion, rather than just simple motion.

For instance, there are three semicircular passages arranged at right angles to each other, called the semicircular canals, which register angular accelerations, but not angular velocities. So, if you turn your head in any plane, one or more of these canals on each side of the head will tell you how your rate of turn is changing. But they will not tell you the actual rate of turn. The reason for this is that the canals contain a fluid, and it is only the motion of this fluid through a canal which will give rise to the sensation of turning.

One end of each canal is partially blocked by a sense organ, the ampulla. When the fluid flows towards this end, pressure on the ampulla is increased, and a sensation of turning is the result. If the fluid flows the other way, pressure on the ampulla is decreased below normal, and again it registers a sensation of turning, but in the opposite direction.

If the canal and the fluid are both at rest, *or* both turning at the same rate, no sensation of turning is registered. But it is registered when a turn is started and the fluid at first lags behind, owing to its inertia; or else when the turn is suddenly stopped and the fluid tries to carry on round the canal for a time, in which case the sensation of turning is false and we complain of giddiness. Thus the ampullae of the horizontal canals will, if you stop turning left, tell you that you have started turning right; but it may be no more true than when a politician tells you the same thing.

It is now known exactly by what sort of messages this information is conveyed along the nerve to the brain. This nerve can only be dissected out satisfactorily in certain kinds of fish whose skeleton is made of cartilage, which is softer than bone.

In 1936 Dr. Otto Löwenstein exposed this nerve in a dogfish, and used an oscillograph to amplify the electrical changes which always accompany the passage of impulses along a nerve. He found that, even when the fluid is at rest in a canal, there is a spontaneous discharge of impulses continually travelling along the nerve; and that this discharge is increased when fluid presses on the ampulla, and decreased when the fluid flows the other way. He found that an acceleration of 3 degrees per second per second in either direction was the minimum that would register.

Dr. Löwenstein has now followed up this success with an even more detailed investigation of the other balancing organs in the inner ear, namely, those which are believed to register gravitational pull. They are two small cavities on each side, called the utricle and the saccule, with a third cavity present in the fish, but not in man. On one wall of each of these cavities is a layer of tissue called the macula. It consists mainly of a layer of "hair cells," each of which ends in a microscopic hair projecting towards the inside of the cavity into a jelly-like layer of sticky mucus.

Embedded in the mucus is a large number of tiny solid particles called *otoliths* (literally "ear-stones"), which consist of crystals of calcium carbonate. It is the inertia of these particles which causes the organ to function, not the inertia of the fluid in the cavity as with the semicircular canals.

Any motion of the otoliths is transmitted through the mucus to the hairs. Large numbers of nerve fibres are seen to ramify between the hair cells, but they do not, apparently, reach as far as the actual hairs, which must therefore exert their effect by distorting the shape of the cells from which they sprout.

The classic authority on this subject, R. Magnus, believed that the strongest stimulus is set up when the macula faces downwards and the otoliths are trying to fall away from it, and that the stimulus is least when it faces upwards, and of intermediate strength when the macula surface is vertical and the otoliths try to move sideways along it. When the human head is held upright, the macula of each utricle is horizontal and looks upwards, while that of each saccule is vertical and looks outwards to the right on the right side, and to the left on the left side. If the head is bent over to the right, the greatest stimulus would therefore come from the right saccule. When an animal is deprived of one saccule, it will incline its head 90 degrees towards that side, as if attempting to equalise the stimulus from each side.

Dr. Löwenstein, in his work on the otolith organs (utricle and saccule), went one better than in his earlier experiments on the semicircular canals. Using a ray-fish, he was able to isolate individual nerve fibres. He found that the nerves from the macula of the utricle, when in its normal position, were transmitting impulses at the rate of 6 to 12 per second. Then, when he tilted the fish's head, either up-and-down or from side to side, the number of impulses along a nerve fibre would increase for one direction of tilt and decrease for the opposite direction.

But a remarkable discovery was that a given direction of tilt might cause an increase of impulse rate in one fibre, but a decrease in an adjoining fibre. In effect, different nerve fibres will sometimes use different codes. And, since the head can be tilted in two different planes, and each fibre might react in one of two alternative ways, the brain has to sort out messages in four different and contradictory languages!

Another noteworthy feature, he found, was that a nerve fibre would not only maintain an abnormal impulse rate as long as the head remained in an abnormal position, but it would do so while the head was in the process of being turned. Unlike the semicircular canals, it could sense a uniform rate of turn, apparently, by registering centrifugal force.

This is not surprising, because the otoliths, owing to their inertia, should

respond to any linear acceleration. Gravity itself is expressed as an acceleration; in fact, Einstein would say that a body at rest on the Earth's surface is not really at rest at all; it is being continually accelerated upwards. This, he would say, is why the otolith organs are sensitive to gravity. Centrifugal force acts likewise as an acceleration, as designers of spaceships are well aware when they propose to rotate the ship in order to give an artificial sensation of gravity.

Dr. Löwenstein's most recent work is on the saccule; he has issued a preliminary report, but full details will not be published till next year. He finds that, in the saccule, one part of the macula responds to gravity just as efficiently as the utricle, though the responses are different in quality. The rest of this macula responds to vibrations, which is not unexpected, as the otolith organs of many fish have been proved sensitive to sound waves. In fact, it was from the otolith organs of the fish that the hearing apparatus of higher vertebrate animals evolved.

Of the questions we now have to discuss, the first is: in the absence of any gravitational datum, what sort of messages would be sent from the macula of each otolith organ to the brain? Among many possibilities, I suggest three as the most likely.

The first is that both the utricles and the saccules would send impulses at the rate which is characteristic for the normal position of the macula in each organ.

The second is that each utricle and saccule might inform the owner that its macula was in the position of minimum stimulation, i.e. horizontal and looking upwards, according to Magnus.

And the third is that no messages would be sent along the nerve at all.

We will discuss each of these possibilities separately.

(1) If, under conditions of no gravity, each of the otolith organs sends out nervous impulses at the rate characteristic for the normal position of the head, we are obviously no worse off than before.

At first sight this seems a plausible suggestion, because the sense organs of the semicircular canals continue to send impulses, even when the fluid is at rest and there is no need to inform the brain that anything unusual is happening. However, Dr. Löwenstein has come to the conclusion, as the result of his experiments, that angular accelerations are registered by the canals in terms of the elastic properties of the sense organ, which means that the latter is still moderately distended when the fluid is at rest, and consequently continues to send out nervous impulses. Minimum distension is only attained when an acceleration is applied that will cause the fluid to flow away from it, whereupon the nervous impulses are diminished and, he says, may even cease.

The sense organs of the utricle and saccule work in a different way, so there is no reason to suppose that, like the semicircular canals, they maintain a normal impulse rate when they have no acceleration to register.

(2) If we believe, with Magnus, that an otolith organ gives minimum stimulation when the macula is horizontal and the otoliths lie on top of it; and if, in addition, we assume that absence of gravity will cause all the otolith organs to register minimum stimulation, then the space traveller's brain will get contradictory messages. His utricles will tell him that his head is upright, his

right saccule that it is tilted 90 degrees to the left, and his left saccule that it is equally tilted to the right.

But Magnus published his opinion in 1924, in his book *Körperstellung* before anyone had recorded the actual messages travelling along the nerves, so it must have been no more than a guess in the dark, based on the idea that otoliths can only cause a stimulus by pulling on the hairs. Yet one would expect that their weight, if pressing downwards on the hairs, could just as readily deform the hair cells among which the nerves ramify, and thus cause a stimulus.

In any case, Löwenstein's only published diagram, so far, shows minimum stimulation with the fish's head tilted 45 degrees downwards, while a neighbouring nerve fibre, as already explained, might well report the same displacement by a different code.

(3) The suggestion that no impulses would be sent from the otolith organs along the nerves at all, in the absense of gravity, seems to me the most plausible of the three. Dr. Löwenstein states that the sense organ of a semicircular canal has, on occasion, sent out no impulses whatever when the fluid has been flowing away from it.

Further evidence is found in the diagram already referred to, which shows the results from a preparation of two or three single utricular nerve fibres. While the fish's head is being lowered from the vertically-up to the horizontal position during 4 seconds, the combined impulse rate along these fibres drops from 85 to only 4 per second. One feels that, if the good doctor could be induced to make a delayed parachute drop from a high altitude, together with his fish and his oscillograph, he might succeed in recording a total abolition of the nerve impulses from the utricle.

The effect of this abolition on a space traveller would be the same as if he were suddenly deprived of all his otolith organs. What would happen then?

A certain proportion of deaf-and-dumb people are permanently without any functioning otolith organs, according to W. Schnell, yet they do not appear to suffer as a result. Schnell reports that a group of deaf-and-dumb children were seen bathing quite naturally, being able to orientate themselves correctly even under water, when bodily sensations of weight would be absent. So the visual sense alone is enough for maintaining balance.

A diver, according to Schnell, can balance himself under water only if he can see. Deprived of his sight, he can only balance correctly on dry land, as the rest of us can do, even with our eyes closed, because the weight of our bodies then enables various sense organs, especially those in our muscles, to give us information about our posture. This is a most important observation. It means that our balancing organs in the inner ear are not capable, by themselves, of enabling us to maintain our balance.

As for the effects of sudden destruction of the balancing organs, this has been done on animals such as the cat and the monkey, and Samson Wright reports that they "soon" recover from the initial symptoms of deprivation, provided they can see, but that they cannot orientate themselves under water. (Presumably he refers here to other animals, since nothing would induce either a cat or a monkey to enter the water.) These animals, therefore, are more restricted than the human organism; deprived of the function of their inner ears,

they cannot balance unless they can both see what is around them and feel the weight of their bodies.

In this connection it is to be noted that an additional function of the utricle is to regulate the action of muscle tone in maintaining balance. But the exercise of this function is not essential for comfort, for it is possible to be comfortable for an indefinite period in a warm bath.

It is evident, therefore, that the so-called balancing organs of the inner ear play only a minor role in the balancing of the human body, and further, that the absence of nervous impulses from them leads to no permanent harm. The only doubtful point is the length of time it would take the body to get used to the sudden cessation of these impulses from the otolith organs, if that is indeed what would happen when the motor of a spaceship is suddenly shut off.

Provisionally, I would hazard the opinion that the crew would quickly get used to it, and thereafter would suffer no discomfort from this cause. But the true answer to the question posed at the beginning of this paper is that I don't know for certain—nor does anyone else.

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Dr. Löwenstein writes that he will be publishing two separate papers, one on the gravity reception and one on vibration reception, in *J. Physiol.* some time in 1950, and that the *S.E.B. Symposium* volume will also contain his recent review of the whole subject of the equilibrium function of the vertebrate ear.

LUNAR SPACESUIT*

By H. E. Ross

(Prepared in co-operation with Mr. R. A. Smith)

Like the spaceship itself, a spacesuit must be designed for the specific job to which it is assigned. For example, just as a spaceship designed to effect a landing on an atmosphered body will differ from one which has to alight on an airless body, so the spacesuit which is to do duty on the Moon will differ in detail from one that has to operate in the presence of an *irrespirable atmosphere*. In the following survey we shall be examining and providing for the requirements of a specified case—viz., a spacesuit designed for service on the surface of Earth's satellite.

The prime considerations are these:—

1. The Moon has no atmosphere—or at any rate all evidence to date points to the conclusion that so far as respiration is concerned it can be regarded as

* *The third paper included in the Society's "Symposium of Medical Problems Associated with Space-Flight."*

Drawn by *R. A. Smith*

An artist's impression of the spacesuit.

airless. (The suggestion, albeit no more than a guess, that an atmosphere may be present *below* the surface, in the caverns, galleries and pipes of an extinct volcanic system, though of very considerable import if true, need not concern us here.)

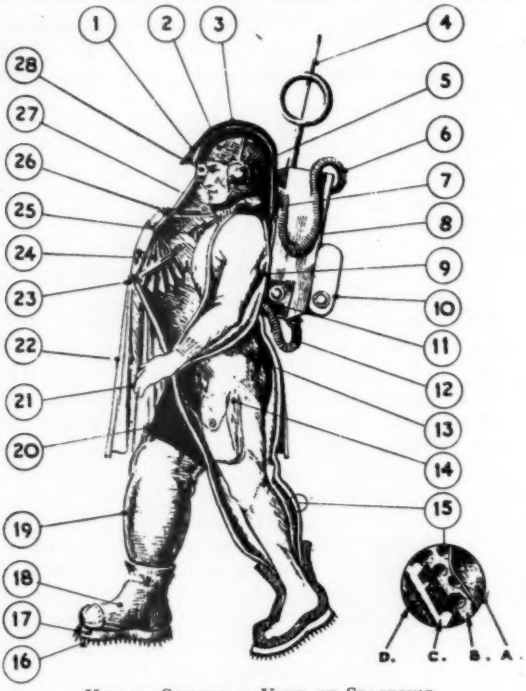
2. Great extremes of temperatures prevail. To be precise, the surface temperatures assigned by astronomical measurement range from a daytime maximum of about 120° C. (248° F.) at the sub-solar point down to about — 150° C. (— 238° F.) on the night side.

Point number one makes two things absolutely imperative. Firstly, the spacesuit must totally enclose the wearer. Secondly, since there is no external air to draw upon, the suit must be entirely self-sufficient as regards oxygen supply—and this entails adequate provision for elimination of the carbon dioxide of respiration and for the removal of excess water-vapour, chiefly that which makes its appearance in exhalations from the lungs. In all, complete and effective air supply and conditioning apparatus must be furnished. Whether this equipment is actually carried or is transported by an attendant vehicle, is a matter which depends upon the circumstances and requirements of operation. However, we shall be taking it that the suit is to be self-contained in all respects, for this permits the greatest freedom of action.

Point number two demands the incorporation of some means of controlling the internal temperature of the suit and requires adequate boot-insulation. The latter is a case of furnishing protection against *conduction* effects: the former involves *radiation* effects, and presents the more variable, complex and formidable problem of the two. It can be said forthwith that it is far easier to defeat a high but steady "impact of calories," or, conversely, defeat a high but uniform rate of *loss* of calories, than it is to maintain the internal temperature of the suit constant in the face of external "temperatures" which vary greatly from time to time. For this reason, it is easier to design a spacesuit for use *only* during the lunar day or *only* during the lunar night, than it is to cater for operation by day *and* night. In this connection it should be noted, that whilst lunar deep-night "temperatures" are doubtless uniformly low, day "temperatures" may vary considerably according to the type of terrain being explored—depending, for instance, upon such things as the cragginess of the surrounding topography, the colour and nature of the rocks, and the amount of shadow cast in the immediate vicinity. In conjunction with other factors, this further implies that the design of a spacesuit for day operation only is intrinsically more difficult than the design of a suit for night operation only—a matter that will become apparent during further discussion. However, the ensemble presented is, in theory at least, competent to cope with any phase of ambient temperature conditions.

Already enough has been said to indicate that the first step towards stabilisation of the internal temperature of the spacesuit is to reduce the rate of gain or loss of calories to a minimum. In practice, this desideratum can be realised by employing a double wall separated by a cellular material offering high resistance to the passage of heat.

As a further precaution operating to the same end the outside of the suit may be provided with a highly burnished metallic film, but, as will be seen later,



KEY TO SECTIONAL VIEW OF SPACESUIT.

1. Anti-glare peak with space for retracting visor.
2. Woollen balaclava head-dress.
3. Double-walled vac-interspaced helmet (bright alloy inner wall; burnished metalised plastic outer wall).
4. Combined D.F. and party conversation aerial.
5. Telephone head-set (or loudspeaker).
6. Air pipeline.
7. Shoulder pads to avoid chafing by helmet.
8. Back-pack containing air and temperature conditioning unit and radio.
9. Roomy armhole to permit withdrawal of arm.
10. Refrigerator (temperature control, mainly day use).
11. Radio control panel.
12. Air pipeline.
13. Woollen garments.
14. Patch pocket.
*15. Four-ply airtight sheath.
16. Articulated and spiked metal undersole.
17. Thermal insulating sole.
18. Pull-on boots.
19. "Silvered" outer surface.
20. Black outer surface (knees to shoulder level).
21. Gloves (these are part of suit; mitts are carried separately for heavy handling work).
22. "Silvered" cape (used to regulate temperature at night).
23. One (of several) stand-off studs.
24. Collapsible air-lock compartment.
25. Electric light.
26. Gasket and fixing ring for helmet.
27. Laryngaphone transmitter mike.
28. 180° vision port.

NOTE.—Patch-pockets repeat on outside of main suit. Hook fitments to facilitate withdrawal of arms from sleeves not shown.

* (15) *A*—Outer cuticle of smooth cloth (non-hygroscopic)
B—Felted cellular lagging (non-hygroscopic).
C—Fabric-backed rubber air-tight sheath.
D—Soft material inner lining (non-hygroscopic).

it might be desirable to have part of the suit furnished with a matt-black finish, in order to provide for the loss of body-heat under certain circumstances.

We are now in a position to review the make-up of the suit material. The drawing shows four distinct layers: (A) a thin exterior skin of closely-woven cloth; (B) a thickish layer (say 1 cm.) of cellular heat-resisting material (as kapok, wool, felt, etc., etc.); (C) the main airtight sheath of fabric-backed natural or synthetic rubber (say 1–2 mm.); (D) an integral interior lining of non-hygroscopic material—this principally for comfort, contact between rubber and skin and absorption of water-vapour being undesirable.

Referring to the airtight sheath (C), there is a point here calling for special attention. Since there will be a pressure inside the suit not counterbalanced by external air-pressure, the suit might become too rigid—to a degree which might inhibit free movement of the limbs, unless such a contingency is guarded against. Indeed, this particular problem has been met in the design of stratosuits. It would seem probable that the incorporation of fabric-backing, by preventing expansion and tensioning of the rubber, would conduce to the retention of flexibility. Even so, specially articulated limb-joints may be required, such as are in fact shown in the main drawing (p. 24). Incidentally, a skin-tight suit similar to that used by "frog-men," but suitably lagged, might overcome these difficulties, at any rate for short duration service.

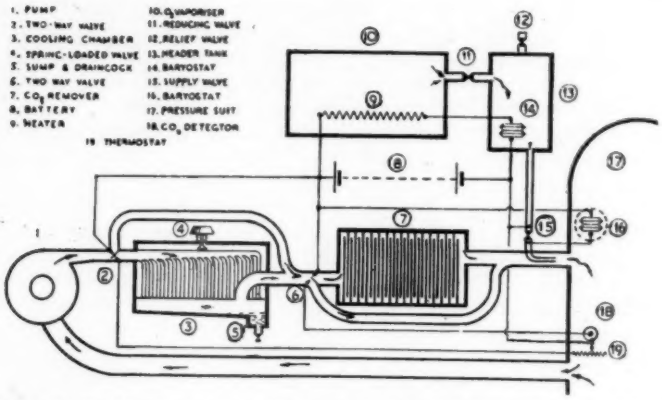
The problem of boot-insulation can be disposed of fairly easily, despite the fact that the temperature of the lunar surface during the day may be oven-high at 120° C. and during the ferocious night as low as — 150° C. For example, the boots might be shod with pattens (preferably articulated), thus minimising the area in contact with the ground. Such a device has, in fact, been employed in the case of some fire-fighting suits (*see Breathing in Irrespirable Atmospheres* by Sir R. H. Davis, Saint Catherines Press). However, the accompanying drawings show 4 cm. thick cellular felted "asbestos" soles, shod with articulated and spiked metal plates for climbing service.

Calculation reveals that with this thickness sole, about 1·27 calories per second will gain admittance under top-temperature day conditions. Conversely, about 2·5 calories per second will pass out through the soles under extreme night conditions. These rates are insignificant (at least in comparison with radiation effects), and in any case can easily be substantially reduced.

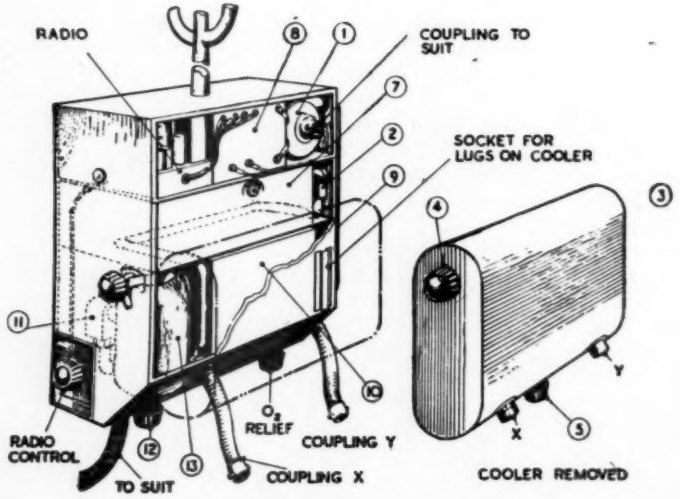
We can now turn to study the helmet. Here it would seem wise to provide the best possible insulation. As the helmet can be a rigid structure, there is nothing difficult about affording exceptionally good heat-insulation, against either radiation "drain" or "gain" of calories, simply by vacuum-interspaced double-walling. The inner shell, which is vital, and must be strong, might be made of a light-metal alloy; the outer shell might be a moulding of some fracture-resisting plastic material.

Since the suit would be used exclusively in almost perfect vacuo, there would be no difficulty about maintaining a vacuum between the inner and outer shells of the helmet. There would be a small hole in the outer shell through which any trapped air could escape. In order still further to resist the passage of heat, in or out, through the helmet, all surfaces would be given a bright metallic finish.

The question as to how one would get into or out of the suit constitutes



Schematic liquid oxygen supply for provision of spacesuit air and temperature conditioning services.



Back-pack layout.

something of a problem. However, zippers with special seals have been used in the case of stratosuits. On the other hand, considering the cardinal importance of avoiding leakage in conjunction with the flexure of the suit during climbing operations, etc., it might be preferable to have the helmet separate, and use this aperture—which would have to be sufficiently large, of course, to clear the shoulders.

The vision-port featured in the drawings consists of a rectangular glass affording 180° of sight. A special glass might be needed to cut down the passage of heat and actinic rays through the window. It will be observed that the helmet is fashioned to provide a shading peak. The object here is to shield the vision-port and the eyes of the wearer of the suit as much as possible from direct sunlight. Again, an external *visor*, of darkened glass or bright metal pierced with cross-slits in front of the eyes, might be incorporated to alleviate the intense glare of lunar daylight and still further reduce the influx of heat through the window. This visor might be attached in such a manner that it could be pushed up into the peak of the helmet when not wanted. It is possible that the glass of the vision-port would have to be warmed during night operations to prevent internal frosting up.

It will be noticed that a small air-lock is fitted in the breast of the suit. In conjunction with a capacious body, loose sleeves, and a straight-fronted helmet, this allows the wearer to pass objects from outside to inside (or vice versa) without breaking the seal of the suit—which would, of course, be fatal. For example, an object gleaned from the surface of the Moon can be placed in the air-lock, the arms withdrawn from the sleeves, the inner door of the air-lock opened, and the object then handled and examined minutely. A further advantage of even greater importance is, that being able to withdraw one's arms from the sleeves of the dress makes it possible to eat and drink whilst wearing the suit. Since this dress is in fact intended for an air and temperature conditioning life of some 12 hours at a stretch, ability to partake of refreshment during exploration is obviously most desirable.

Owing to the extreme heat and cold of lunar conditions, thick gloves or mitts would be needed, if much handling of materials, objects or tools obtains, or during periods of climbing. Indeed, it may be necessary to incorporate electrical warming of the hands during night operations involving heavy work. Again, knee-padding will probably be necessary for mountaineering. It will further be noticed that a chair in the shape of a "shooting-stick" has been provided—the rocks of the Moon not being at all attractive as seats, owing to the extremes of temperature prevailing. Even the shooting-stick chair will be either very hot or very cold, but since its area of contact with the ground is insignificant and its mass small, it should be reasonably satisfactory. In any case, it could be electrically warmed for night operations, if necessary. . . . Incidentally, during long treks some provision for sleeping must be made. However, in this case a pressurised and insulated vehicle might be presumed to be in attendance. Otherwise, camp-beds and silvered tents might serve to insulate the sleepers from the ground and mitigate radiation effects.

One or two other special features of the suit illustrated remain to be discussed at an appropriate juncture, but the following is worth comment immediately.

In order to secure maximum comfort the suit should be truly personal in the sense that it ought to be "made to measure." Even so, it would seem that one extra precaution may be necessary, in that some way of keeping the helmet seated on the shoulders might be required; otherwise the expansion of the suit under vacuo would perhaps result in the helmet standing too high, so that the level of the eyes does not correspond with the vision-port. This ludicrously forlorn appearance is in fact, noticeable with some prototype stratosuits. A possible solution to this difficulty would be to pad the inside of the shoulders of the dress and employ internal body-hardness to keep the helmet down to proper eye-level. . . . Moreover, the looseness of the sleeves of the particular suit under discussion may render this precaution absolutely essential.

It will be convenient to commence discussion of the various services contained in the "back-pack," which is a double-walled, heat-insulated box attached to the suit by integral harness, by brief consideration of the radio gear. In the first place, it is necessary to point out that we cannot legitimately count on radio ranges beyond the visual horizon whilst on the airless Moon—at any rate if high frequencies are used for communication.

In this connection, it may be remarked that to a person whose eye is 5 ft. 6 in. from the ground, the distance to the lunar horizon, across a level plain, would be 1·5 miles. Under these conditions, an object (say a spaceship) 50 ft. high would just be visible at 6 miles. The corresponding terrestrial figures are 2·86 miles and 11·46 miles*.

However, extreme range radio, though a convenience and useful safeguard against getting lost during long treks, is not absolutely essential so far as the spacesuit is concerned. Using existing technique, it should easily be possible to carry radio capable of rendering party conversation up to the limit of the lunar horizon. Moreover, and by way of example, the drawing depicts the incorporation of a "loop," for the identification of the direction of emanation of a signal, thus facilitating homing on the spaceship base or rendezvousing in a particular locality during exploratory trips. Homing over considerable distances could, of course, be coped with by establishing a chain of repeater stations.

The next feature introduces a most vital item—the oxygen supply.

Here there are several preliminary considerations: is it to be a "natural" 21 : 79 oxygen-nitrogen atmosphere, or a special mixture, or pure oxygen? . . . It can, in fact, be any of these, though preferably pure oxygen.

Several correlated factors sway the decision in favour of pure oxygen. For one thing, with a natural oxygen-nitrogen atmosphere there is some risk of the "bends" (a painful and dangerous condition due to bubbles of nitrogen forming in the blood), which might occur if the pressure inside the suit fell suddenly through any reason, as in the case of a bad leak. Obviously, the leak itself might prove fatal to the wearer of the dress, but it would be wise to avoid the secondary issue if at all possible. However, with a special mixture, such as oxygen-helium or oxygen-argon, where the inert component of the atmosphere

* Horizon distance (d) = $\sqrt{2\,hr}$.
where h = height
r = radius of body.

does not dissolve so readily in the blood as does nitrogen, risk of the "bends" would be practically eliminated. Breathing mixtures of this type are in fact commonly used for many purposes, and in closed-cycle gear it is only necessary to replace the oxygen consumed by the body, the inert component of the mixture remaining unconsumed. (This is, of course, also true of a closed-cycle system using ordinary air.)

However, it is in fact possible to dispense with the inert "diluent" altogether —at any rate it seems safe to do so over quite long periods without harmful physiological reactions. There is only one proviso here: if pure oxygen is breathed its pressure must approximate to normal. Actually, it should be round about 160 mm. of mercury, the same as the partial pressure of the oxygen component of ordinary air at sea-level. A pressure as low as 80 mm. can, however, be used, if physical exertion is slight and the period not unduly extended. On the other hand, oxygen pressures greatly in excess of 160 mm. are dangerous—for one thing, tending to engender pneumonia.

The advantages of using pure oxygen at, say, 160 mm. pressure, or thereabouts, are two-fold. Firstly, the dress will be much more flexible than if distended by an atmosphere of mixed gases (normal air, for example, corresponds to about 760 mm. pressure). Secondly, the lower the pressure the less will be the loss due to leakage.

The next point concerns the source of the oxygen. Three alternatives immediately present themselves—viz., compressed ("bottled") oxygen; liquid oxygen; hydrogen peroxide.

Here there is little doubt as to the choice. Provided only that the containers are not too bulky or too weighty, compressed oxygen offers the simplest supply. In view of the fact that on the Moon the weight of all things is reduced to one-sixth of the terrestrial weight, it would seem probable that a compressed oxygen supply sufficient for 12 hours' service could be carried with comparative ease—and without unreasonable bulk. However, for sake of example the schematic drawing depicts the kind of arrangement that might be used if liquid oxygen is employed. The disadvantage with liquid oxygen is, of course, that the container must be exceptionally well heat-insulated, otherwise the liquid will boil. This might lead to excessive waste, even if risk of the container bursting did not arise. Owing to the intense heat of the lunar day, it would seem that a liquid oxygen supply should be avoided if possible in the case of operation by day.

The other alternative, hydrogen peroxide, at high concentration, is worth considering, but the necessary catalysis introduces complications. Furthermore, the unavoidable "water content" of hydrogen peroxide makes for unwanted weight. However, even so, a hydrogen peroxide system might compare favourably with "bottled" oxygen gas. (Note: it would be difficult, though not impossible, to use the water component of hydrogen peroxide for drinking. However, the complexity entailed in separation, etc., renders this possibility unattractive.)

The rate at which oxygen must be supplied is the next thing to engage the attention. Here it will be convenient to insert part of the Standard Table, viz.:

RESPIRATION TABLE (HALDANE).

Normal requirements PER MINUTE *for normal temperature and pressure at sea-level.*

Work level.	Oxygen required.	
	Litres.	Grams.
Rest in bed	0·237	0·3387
Rest standing	0·328	0·4687
Walking on grass at 2 m.p.h.	0·780	1·1146

It is not necessary to continue the table to include figures for greater exertion, because in the case of the Moon, where only one-sixth g. obtains, we may reasonably assume that the 2 m.p.h. work-level would be a satisfactory basis of average consumption.

The next thing is to provide some way of keeping the atmosphere of the dress reasonably pure. In other words, provision must be made for the elimination of the carbon dioxide exhalations of respiration. At the 2 m.p.h. work-level, this entails removing carbon dioxide at the rate of 0·662 litres (1·3087 grams) per minute.

Here we should note that the presence of up to about 1 per cent. of carbon dioxide in breathed air is permissible for considerable periods. On the other hand, it is not necessary, or even desirable, to seek the complete elimination of carbon dioxide, for it has been established that the presence of a little carbon dioxide helps to stimulate respiration. Actually, the important point is to make sure that the purifying apparatus is competent to remove at least 0·662 litres of carbon dioxide per minute over the period catered for in oxygen supply.

It will not be possible to discuss here the comparative merits and demerits of all feasible methods of eliminating the carbon dioxide exhalations. However, it should be borne in mind that the degree of compaction and minimisation of weight essential in the case of a spacesuit severely limits the choice of method. For example, it would be comparatively easy to flush the suit continuously with pure oxygen, whilst at the same time permitting the foul air to escape. In practice, however, this arrangement demands so much oxygen that the service life of the kit would be gravely curtailed by the excessive weight of oxygen that would have to be carried.

After all factors have been considered, it would seem that for the time being at least we must rest content with basing the elimination of carbon dioxide pollution on chemical agents. Here there are several substances which, in the presence of water-vapour, are capable of extracting carbon dioxide from air. Two of these materials are especially worthy of consideration—viz., sodium hydroxide and sodium peroxide. However, since sodium peroxide possesses a very great advantage over sodium hydroxide, in that Na_2O_2 actually *evolves oxygen* whilst absorbing carbon dioxide, our choice finally devolves on this material. As a matter of fact, special preparations based on sodium peroxide, and in some cases incorporating an "activator," are commonly employed in various types of "breathing kits" designed for a wide range of uses, including

diving, mountain climbing, high-altitude flying, mining, and general work in irrespirable atmospheres.*

Now, mention has just been made of the fact that sodium peroxide yields oxygen in process of taking up carbon dioxide, and manifestly this is a very useful attribute. Using sodium peroxide does in fact permit a considerable reduction in the weight of oxygen that has to be carried to furnish a given number of hours' service—or, alternatively, more hours of operation can be obtained without increasing the weight of oxygen carried. It should, however, be understood that, of course, the actual rate of consumption of oxygen is unchanged—the "additional" oxygen being a "regain" from the carbon dioxide-sodium peroxide reaction. The extent of the saving in weight of oxygen needed for a given time might be as much as 43 per cent. with an efficient "regenerative" system using sodium peroxide.

As a final note, it may be mentioned that the efficiency of the CO_2 absorbent depends to a large extent upon the effective display of the sodium peroxide to the atmosphere which is to be purified. A number of devices are employed with the object of increasing efficiency in this respect, and the absorbent is sometimes formed into pellets, or briquettes, or is held in a framework of grids. The drawing shows the latter arrangement. Sometimes as much as four times the quantity of chemical theoretically required is actually supplied, to cover "reaction inefficiency": with careful design much less should suffice.

Besides the elimination of carbon dioxide, it is necessary to make arrangements for drying the atmosphere of the suit. Why this is necessary will become apparent when it is stated that, at the 2 m.p.h. work-level, the lungs and skin together yield something like 108 grams (3·8 ozs.) of water-vapour per hour.

Manifestly, if this discharge of moisture is not removed, then the atmosphere of the dress will become exceedingly damp—a condition not at all in keeping with the high standard of comfort desired. Indeed, quite apart from other considerations, the degree of humidity plays an important rôle in determining how warm one feels. For instance, if the concentration of water-vapour in the surrounding air exceeds 50 per cent. of the saturated value, the moisture of perspiration cannot easily leave the skin; under which circumstances the body has difficulty in disposing of its surplus warmth. Conversely, if the air is too dry, then evaporation proceeds rapidly and the body loses heat too quickly, leading to a sensation of chill. Moreover, entirely desiccated air is undesirable because the presence of a little water-vapour assists in keeping the respiratory channels moist.

Fortunately, the sodium peroxide (or sodium hydroxide) used to remove CO_2 will also take up moisture, so that, by and large, there is not much to worry about on this score—provided, of course, that a sufficient quantity of the chemical is furnished to cope with both requirements. As a matter of fact, in any case the kit exhibited in the drawings provides additional drying as an incidental concomitant of temperature conditioning. How this comes about will be discovered in the course of the following discussion.

Even if the insulation of the dress was perfect, so that no heat escaped or

* *Sir Robert H. Davis's books "Breathing in Irrespirable Atmospheres" and "Deep Diving and Submarine Operations."*

gained admittance, it would still be necessary to make arrangements for the loss of about 33 calories per second, because, under conditions of normal exertion, and with the surrounding atmosphere at "normal" temperature, the body disburses some 33 calories per second.

However, the insulation of the dress cannot be rendered perfect: there will, in fact, be some heat passing into the suit when there is daylight, coming directly from the sun and indirectly by reflection from the surrounding very hot terrain, while at night there will be radiation of calories from the suit to space and to the surrounding very cold terrain. Moreover, there will be a little loss of heat through the boots at night to the intensely cold ground and a little influx of heat *via* the boots in daytime, from the intensely hot ground. However, in comparison with *radiation* gains and losses, "boot-leakage" by *conduction* is likely to be insignificant.

Obviously, the interior of the suit, in particular its "atmosphere," must be maintained at a constant, or nearly constant, temperature—say within + or − 5° of a mean of 18° C.—irrespective of "surrounding temperatures," which may be anything from about − 150° C. (or perhaps much less) up to 120° C. Moreover, the required temperature of 18° C. must be held constant at all levels of exertion from that of "rest" to at least the equivalent of light work.

Now, fortunately, there seems to be no difficulty in providing the suit with good insulation under night conditions. Indeed, the thermal insulation of the suit can easily be made *too* good. In the case of operations by day, on the other hand, special arrangements have to be made to provide *cooling*. In both cases, however, regulation of the internal temperature of the suit—preferably automatic regulation—is, of course, essential.

Confining our attention for the moment to night operations, and bearing in mind the fact that a bright metallic finish to the exterior of the suit will cut the rate of emission of calories to a minimum, whereas a matt-black finish would permit much more copious loss, it becomes apparent that one way of obtaining the necessary temperature regulation is by varying the "colour" of the suit.

The *cape* shown in the drawings demonstrates how, in effect, varying the colour can secure temperature regulation.

Firstly, all parts of the suit with the exception of the chest-area would be brightly "silvered." This would ensure that the limbs and head never stand in danger of becoming too cold. The chest area, on the other hand, would be provided with a matt-black finish. If necessary, the lagging of the suit over the area of the chest could be reduced in order to increase the maximum rate at which calories can be lost.

The cape would be made of some very light fabric, brightly "silvered" inside and out to afford maximum reflection. Control of the internal temperature of the suit would be obtained by exposing more or less of the black chest-area, the reflecting properties of the *cape* being effective in preventing the escape of calories. Conversely, the "silvered" surfaces of the *cape* will operate to cut the rate of transmission of calories *inwards* during daylight.

However, in order to secure the greatest possible range of control it would be necessary to prevent contact between the *cape* and the body of the suit so far as is practicable, otherwise heat will pass by conduction. In other words,

the *cape* should be "stood-off" from the suit. This insulation might be obtained by furnishing the chest-area of the suit with a number of protruding studs.

Although precise calculation is obviously extremely difficult, it can be stated that a difference of some 44 calories per second could be obtained by this method—which, all things considered, should be an ample range of control.

The case of temperature regulation under day conditions now requires investigation. Here it is necessary to bear in mind that there will be a tendency for the suit to accumulate heat because it is exposed to sunlight (either direct or reflected), that a little heat will get in through the boots, and that in any case some 33 calories per second of body-heat must be lost. Moreover, the increment due to sunlight will be a highly variable factor, depending, among other things, upon the proportion of the suit-area illuminated as against that which is in shadow.

However, rough calculation (which under the circumstances can only be regarded as approximation) indicates that arrangements must be made for the continual disbursement of some 60 calories of heat per second during the whole period of day operation. Since the *cape* can give no assistance here (if used, it would in fact, have to be kept buttoned up during daytime), we have to seek other ways of losing heat from the suit.

The overriding consideration of simplicity is a factor which would seem to point to the desirability of employing a system of vaporisation-refrigeration. Here, in principle, it is only necessary to circulate the atmosphere of the suit through a system of pipes immersed in a low boiling-point liquid—such as, for instance, pure ammonia. (As a matter of fact, ordinary water might be effective under certain conditions.) Exceptional vaporisation can be promoted by reducing the pressure over the refrigerant. This is something which can, of course, easily be arranged simply by exposing the liquid to the vacuum of space, control of the rate of vaporisation (and hence disbursement of calories) being obtained by a thermostatically-operated valve (4 of the schematic drawing).

In order to gain maximum "life" from a single charge of refrigerant, it would be possible to arrange for the liquid to start super-chilled. However, this freezing might well entail providing the spaceship with apparatus for pre-conditioning the cooling units immediately prior to use.

One collateral advantage of vaporisation-refrigeration is that the coolant will "boil away" during use, so that some of the weight carried disappears during service. On the other hand, arrangements can be made to avoid vaporisation; in which case the number of hours service will be decreased, *but the refrigerant can be used again and again*. It would, in fact, be possible to regenerate the cooling units simply by exposure to lunar night conditions, or, during the daytime, by leaving them for a time in a shady spot.

Incidentally, if a *cape* is used for temperature regulation at night, then the cooling unit is not needed, or, if carried, can be by-passed.

It now only remains to point out, that the temperature of the air will be reduced during passage through the cooling unit (generally to below the dew-point), and therefore water will be precipitated. This is fortunate because it helps to reduce excessive accumulation of water in the carbon dioxide extraction

unit. The schematic drawing shows the water catchment sump of the cooling chamber, and the CO_2 absorption unit would, in fact, be similarly equipped.

This brings to an end the present survey of spacesuit requirements. The principle features have been covered, but a complete book would be needed to treat each feature in detail. To conclude, it is estimated that the weight of this suit, charged for a 12-hour life, would be of the order of 150 lb. However, on the Moon the weight would be equivalent to only 25 lb. or so.

DISCUSSION

DR. JANSER raised the question of life in an artificial atmosphere. It had been proved possible to live for a time on oxygen, alone or mixed with various other gases, but in some cases symptoms of anoxia had developed after two weeks. Furthermore, although negative ionisation of the atmosphere does no harm for short spells, it might prove harmful if continued for a long period.

Decrease or lack of gravitational pull might also prove harmful. He had recently been down a mine-shaft, and had experienced a rush of blood to the head. This would increase the vagus tone, and decrease that of the sympathetic nervous system, which controls the tone of the intestines, etc., and of the vascular system. As to the orientation, our muscle sense is our principal gravity sense, rather than the inner ear.

DR. E. T. O. SLATER replied that sudden changes in bodily position could give rise to unpleasant effects for a short time, but the body quickly adjusts itself by altered tone to suit the new conditions. Concerning the absence of gravitational pull, it would give rise to a consistent feeling of continual falling. The crew of a spaceship should take all possible measures to avoid every form of discomfort, including this one, and he advocated rotating the ship to provide a substitute for gravity if it were at all possible to do so.

A. C. CLARKE said the temperature of 248° F. on the Moon, mentioned by Mr. Ross, is only found at lunar noon; in the afternoon and morning, even at the Equator, the temperature is no hotter than that of rocks on the earth exposed to the sun.

Regarding accelerations at take-off, they need not be so high in the interests of economy as Dr. E. T. O. Slater suggested; for instance, a rocket ascending with an acceleration of 1 g. would reach orbital velocity in 800 seconds, or with 4 g., in 200 seconds.

One question to which he had never heard a clear answer was: If a man suddenly enters a vacuum (from an atmosphere without nitrogen) what will he die of—the immediate disruption of his lungs, or relatively slower suffocation?

DR. E. T. O. SLATER, in answer to the last question, said he believed that death would ensue from lack of oxygen to the brain, which, if deprived of oxygen would immediately be put out of action and could never recover.

DR. A. E. SLATER said that it could not be held that the absence of gravitational pull in any particular direction could lead to unpleasant symptoms. We could lie on our backs or stomachs, or on our right or left side, or we could stand on our feet, or on our head. In each case, gravitational pull acted in only one direction and was absent in the other five, and the only unpleasant position, that of standing on our head, was harmful because of gravitational pull, not its absence.

A. V. CLEAVER mentioned that experiments in Germany had shown that a man could withstand 15 g. when lying prone.

R. A. SMITH asked whether the crew would be likely to suffer from claustrophobia. Also, although Dr. E. T. O. Slater, in his paper had discounted the possible risk of picking up infections, the body could nevertheless be affected by chemical and mechanical irritants, of which pollen was an example.

He also asked whether, in an air-conditioned plant, there was not great danger of cumulative bacterial contamination.

DR. E. T. O. SLATER replied that claustrophobia is an anxiety reaction which should be discoverable before the voyage began. In fact, it would be a good idea to shut up the crew in a model spaceship for a fortnight, in order to discover what risks were likely to arise.

H. E. Ross stated that it had been shown possible to hold the breath for 15 minutes 13 seconds, after forced breathing of oxygen for some time beforehand. However, this was merely a matter of interest, and obviously not a practical alternative to the spacesuit.

A member discussed the possibility of rotating the spaceship in two halves with a cable between, but the cable, he said, would be unlikely to stand the strain if the rotation were sufficiently fast to replace gravity.

Another member asked what effect a strong magnetic field would have on the propagation of electrical impulses along a nerve.

DR. A. E. SLATER replied that a nervous impulse was not an electric current, but a chemical change, whose progress along the nerve was accompanied by minute electrical and other changes.

A. C. CLARKE added that magnetic fields much stronger than those familiar on the Earth would probably not be encountered. In any case, people sometimes put their heads inside an induction furnace for a short time to make adjustments, and came to no harm from the very strong magnetic field to which they exposed themselves.

A questioner asked about the effects of punctures caused by meteors.

H. E. ROSS, replying, said that statistically the risk seemed negligible, but jocularly suggested that a puncture repair outfit might be carried. He pointed out, however, that a hole might sometimes occur in a rather inaccessible area, and in any case the wearer too, ran the risk of being permanently punctured.

Finally, before closing the meeting, A. V. CLEAVER pointed out that there was not an indefinite limit to the gain in fuel economy which could be obtained from increased accelerations, because the structure of the ship as well as of the crew would have to stand up to them, and the increased structure weight would more than offset the gain beyond a certain point.

FOURTH ANNUAL GENERAL MEETING

The Society's Fourth Annual General Meeting was held at St. Martin's School of Art, Charing Cross Road, W.C.2, on December 9, 1949.

After the Accounts had been approved, the Chairman went on to give the main points from his printed address (which had previously been circulated to all members with the Annual Report), and added some further comments and explanations in regard to the Society's affairs for the past year.

The Report of the Scrutineers was then presented. A total of 227 ballot papers had been received, all of which were valid. The names of those elected to the 1949/50 Council were as follows:—

A. V. Cleaver	W. H. Gillings
K. W. Gatland	G. V. E. Thompson.

The Chairman welcomed Mr. Gillings to the Council, saying that he had been a staunch supporter of the objects of the Society for many years, and had assisted in the original formation of the Society in London in 1937. It was also a pleasure that Mr. Gillings had been elected under the new provisions of the Society, which enabled Members to serve on the Council for the first time. Mr. Gillings replied suitably.

The last formal business was the approval of a resolution that the authorised number of the Society's members should be raised from 600 to 800, in view of the continued increase in membership. This was unanimously approved.

After the transaction of the formal business, the meeting was then thrown open to general discussion, the Chairman inviting queries, comments, and suggestions, on any aspect of the Society's affairs.

A large number of questions were asked and a most interesting discussion took place, during the course of which several valuable suggestions for future activities were received.

Subsequently, at the first meeting of the new Council, Mr. A. V. Cleaver was re-elected Chairman of the Society for the 1949/50 session.

M. Robert Esnault-Pelterie.

M. ROBERT ESNAULT-PELTERIE

Members of this Society know M. Esnault-Pelterie as one of the great pioneers of space-flight, one who was proclaiming its ultimate practicability even as far back as 40 years ago, and as the author of the two classics, *L'Astronautique* (1930) and *L'Astronautique complément* (1935). It is unlikely, however, that many of our readers are fully aware of the vast background of technical work, especially in aeronautics, against which these astronautical studies should properly be viewed, and we greatly regret that the space at our disposal does not permit us to do it full justice.

Born in 1881, M. Esnault-Pelterie as a boy showed a lively taste for things mechanical, and was encouraged in this by his father, who provided him with a workshop and laboratory in which to develop his interests. In his autobiography published in 1931 (*Vie et Travaux Scientifiques*; publisher, Henri Tissier, Orléans), he comments that at first, "this taste centred especially on railway trains, the only mechanical vehicles of that period"—a striking illustration of the speed with which modern technology has advanced. Later, his amateur youthful studies shifted to physics and chemistry, and by 1902 he had taken out his first patent on a radio set of his own design and construction; ever since then, he has continued to invent an amazing variety of things, and altogether has had 120 patents issued to him.

His orthodox technical education was at first directed towards medicine, but earlier interests reasserted themselves, with the result that he finally graduated in physics and chemistry also. From 1902 to 1903, he discharged his obligations for military service in the French Signal Corps under General Ferrié and, on being released from this, settled down to serious study of the problems of mechanical flight, in which his interest had been growing for the past few years.

M. Esnault-Pelterie's first essay in aviation was to construct, in 1903, a glider based on the published designs of the American brothers Wright. Stability difficulties with this led him to conduct certain aerodynamic experiments with aerofoils mounted on the top of a specially designed automobile, driven at high speed along a straight stretch of road between Vierzon and Sallris, where the sheltering forests alongside prevented any inteference from side-winds (90 km./hr.—"considérable à l'époque," as his autobiography observes). In parallel with these activities, M. Esnault-Pelterie devoted much thought to the question of a suitable engine. After detailed theoretical studies, he rejected the gas turbine as being impracticable for the moment, although potentially ideal, and set himself the task of designing and constructing his own motor of the reciprocating type.

All this work culminated in the first R.E.P. aeroplanes, which were an amazing anticipation of the practice of to-day and introduced for the first time many features which are now standard. They were all-metal (fabric-covered) monoplanes and their R.E.P. engines, of the radial air-cooled type, with an odd number of cylinders, drove metal tractor airscrews. The stability was controlled by means of a lever which could be moved in every direction, which is now known as the "joy-stick." Even their undercarriages were of the "bicycle" type, only

now becoming fashionable on high-speed jet aircraft, and incorporated oleo-pneumatic shock absorbers! The first one flew in 1906, at a time when no contemporary flying machine incorporated such advanced ideas. It is interesting to note that the great British Vickers concern, in the early years of its aviation department, worked with a R.E.P. licence, and aircraft produced by Esnault-Pelterie scored many notable successes in the years before the Great War of 1914–18.

M. Esnault-Pelterie did his own test flying, and in 1907 secured French pilot's licence No. 4 in one of his own machines. These all employed the modern "joy-stick" system of control from the start, the patent rights on which were a source of immense trouble to their inventor after his activities as a constructor were forced to a halt, in 1913, by the lack of official support, which is often the sad lot of the pioneer.

Following this setback, M. Esnault-Pelterie continued to exercise his ingenuity on a great variety of subjects. During the war years and those which followed, automobile suspension systems, hydraulic transmissions and pumps, tidal power, and a novel form of internal-combustion engine (the "ballistic motor," in which the pistons transmitted their energy hydraulically, instead of through the intermediary of a mechanical crank system), all occupied the attention of his fertile mind.

It is against this background, of a wonderfully creative life typifying the very spirit of our age, that we must consider Esnault-Pelterie's work on inter-planetary flight, which may yet prove to be the thing for which he is most remembered. In 1912, he lectured on this subject to the French Physical Society; as recently as 1947, he delivered a paper to L'Aero Club de France on the possibilities of atomic energy for astronautics. Between these dates, and while he was engaged on all the less visionary, though still highly original, engineering developments already described, he found time to write his famous books. He was also co-founder of the international R.E.P.-Hirsch Prize for achievements forwarding the progress of astronautics, which was first won by Prof. Hermann Oberth, with his *Wege zur Raumschiffahrt*. Less well known are his practical experiments on rocket propulsion.

In 1931, he was experimenting, with limited and rather unsatisfactory private resources, on tetranitromethane as a rocket propellant—the earliest occasion on which we know any work of this nature to have been carried out, though this compound has received some serious study recently as an oxidiser of desirable properties. During these experiments, M. Esnault-Pelterie was seriously injured in an explosion, losing the fingers of his left hand, but they led to the provision for him, by the French Air Ministry, of improved (though still inadequate) test facilities.

One consèquence of this new official backing was that little was published of the results obtained after 1931, since the authorities insisted on their being kept secret. Also, since the experimenters had to leave Paris hurriedly in 1940, at the time of the German invasion, most of the records were lost. However, it can now be stated that in 1939, M. Esnault-Pelterie had succeeded in producing a rocket-motor burning petrol and liquid oxygen, which gave its calculated exhaust velocity (2·4 km./sec.) and thrust (300 kg. for 55 secs.)—a performance

which would have been sufficient to propel a 100 kg. rocket, of the type envisaged, to an altitude of 100 km.

Our picture shows M. Esnault-Pelterie in the uniform of L'Institut de France, the great cultural body of which the French Academy is a part and of which he is a member. He is also a member of many other technical societies, including La Société des Ingénieurs Civils de France, and a past-President of several of them, including La Société des Savants et Inventeurs de France. He now lives in well-earned retirement in Switzerland, respected and honoured by all those with interests in aviation and technology in general, but astronautics in particular.

REVIEWS

The Conquest of Space

(Paintings by Chesley Bonestell; text by Willy Ley. Pp. 160, 18 fig., 48 plates (16 in colour). $3·95. Viking Press, New York. 1949.)

The eagerly-awaited Bonestell-Ley book has at last arrived, and it proves to have been well worth the waiting. Magnificently produced, it is extraordinary value for the money and the publishers are to be congratulated on their boldness and enterprise. It is a large book—11 in × 8¼ in.—and besides many line drawings, contains 48 plates, 16 of them four-colour reproductions. (It is pleasant to record, incidentally, that the colour plates were made in England, where apparently this sort of thing is done better than anywhere else. It is not so pleasant to record that the British Customs held up the original plates five weeks while the red tape slowly unwound. We also do this sort of thing better than anyone else!)

The book has a splendid cover-jacket showing, on the front, the lunar rocket painting which has already been used as a cover of *Astounding Science Fiction*, and on the back, what is perhaps the finest of all Bonestell's works—the thin rind of Saturn, almost "new" and with the rings nearly edge-on, against the deep blue of Titan's sky. (Titan, of course, being the only satellite which could have a blue sky.)

Of the interior illustrations, the black-and-whites would have been sufficiently impressive in themselves, but they inevitably lose by contrast with the colour plates. Is it too much to hope that when *The Conquest of Space* becomes the success it deserves to be, the proportion of colour to monochrome may be gradually increased? The reviewer would have given a good deal to see the "Great Wall," the Alpine Valley, Copernicus, Saturn from Rhea, and Jupiter from Satelitte V in colour, and is only reconciled to the monochrome of the view over Theophilus, Saturn from Phoebe, and Saturn from Dione, by happening to possess coloured reproductions from other sources.

The colour plates are, going through the book, as follows: preparing the rocket for its trip to the Moon (in the reviewer's opinion, the least successful of the plates, since it somehow lacks the Bonestell touch and might have been done by any merely competent artist); the Leibnitz Mountains during an eclipse of the Sun by the Earth; view from the South Pole of the Moon, with the Earth on the horizon; the rocket on the Moon, ready for the return; the

surface of Mercury; the surface of Venus; Martian landscape seen from the polar cap; Mars seen from Deimos; Saturn from Japetus; Saturn from Titan; Saturn from Mimas; the double star Mira from a hypothetical planet; Martian landscape, green areas; Martian landscape, desert areas; surface of Jupiter; and Saturn's rings from the surface of the planet.

Willy Ley will no doubt be resigned to having his text overshadowed by the paintings, but he is by no means the junior partner in the enterprise. In a rather short space he has given a remarkably detailed and thorough account of the subject, covering the theoretical principles of astronautics and, on the astronomical side, giving a clear account of the Solar System and the characteristics of the planets. (Though it is a little surprising to find one of the four chapters devoted entirely to the asteroids.) Some of the statements in the astronomical section may be regarded as rather dogmatic, though probably Ley would defend this on the grounds of lack of space. In particular, it is somewhat surprising to find it stated more or less flatly that the Lunar craters are meteoric in origin; there is no indication of the fact that a substantial proportion of astronomers—if not a majority—thinks that the meteoric theory is quite untenable.

The text is often dramatic—as in the opening passage describing a typical White Sands launching—and frequently amusing. This sentence will appeal to many: "The layman may dream of a rocket which has a take-off weight of 33 tons for every ton of remaining weight, but the designing engineer would not touch the job and would indeed, gladly furnish the applicant with the addresses of his competitors."

It is much to be hoped that this fine book will become available in this country, despite present difficulties. No better introduction to astronautics could possibly be imagined, and many will echo Dr. Robert S. Richardson's remark, "I only wish that a book containing such illustrations could have fallen into my hands when I was a youngster." It is probably destined to fire many imaginations, and to change many lives in the years to come. A. C. C.

Konstanin Eduardovich Ziolkovsky
(1857–1935)

(By Professor A. A. Kosmodem'yanskii. Published by *Pravda*, Moscow. 1948. 32 pp., 60 copecks, paper cover. *In Russian.* Distributed in England by Collet's Russian Bookshop, 67, Great Russell Street, W.C.1, price 6d., including postage.)

A small booklet now available in this country contains a verbatim report of a lecture given to the All-Union Society for the Diffusion of Political and Scientific Knowledge (U.S.S.R.) dealing with the life and work of Ziolkovsky.

Ziolkovsky was born in the village of Izhevsk, in the Ryazansk district on September 17, 1857. He became deaf as a result of an illness at the age of 10, and his schooldays were thus abruptly closed. However, he began to read in his father's meagre library, and became interest in science when he was 14. At this time he also began to build various models. At 16, he went to study in Moscow, practically the whole of his allowance being used to purchase books, instruments, chemicals, etc., while he existed himself on black bread and water.

Three years later he returned home and began teaching. The greater part of his life was spent as a teacher, first at Borovsk, and later at Kaluga.

Ziolkovsky was interested in several fields of science, but in 1885 began to work on aeronautical problems, designing an all-metal dirigible and a monoplane with curved, bird-like wings in 1895. In 1897 he built the first wind tunnel in Russia. On becoming acquainted with the works of Jules Verne he began to study rockets, and in 1903 the Russian journal "Scientific Review" (*Nauchnoe Obozrenie*) published his article, "Investigation of Planetary Space by Reaction Machines."

The rest of his life was then devoted to an investigation of the problems of rocket flight and interplanetary travel.

It would be wrong to criticise his work too severely. He was a pioneer, and it is hardly to be expected that everything would have stood the test of time. (Thus a rocket designed in 1914 is provided with an extremely long combustion chamber arranged in intricate coils.) It is far better to recognise his positive contributions to astronautics, and his farsightedness in visualising passenger rockets powered by liquid oxygen and either liquid hydrogen or a hydrocarbon. Many equations which he derived are also still in use.

Like many other pioneers, Ziolkovsky had to wait until the last years of his life for recognition of his work. G.V.E.T.

The Atmospheres of the Earth and Planets

(Various Authors. Edited by Gerard P. Kuiper. University of Chicago Press, 1949; viii + 366 pp., 16 plates. $7·50.)

In September, 1947, a symposium on Planetary Atmospheres, sponsored by the University of Chicago, was held in connection with the 50th anniversary of the Yerkes Observatory. The papers presented, in many cases revised and brought up to date by their authors, have now been edited by Dr. Kuiper and published under the above title, and the result is a volume of immense value.

This is definitely not a "popular" book, as a sound knowledge of mathematics is essential for its proper appreciation, but parts of it can profitably be studied by those not so equipped. Meteorologists, astronomers and geologists alike will find it of great interest, and there is much material of value to members of the B.I.S. If we mean to travel to other worlds it is essential to find out as much as we can about their gaseous envelopes, and as well as summarizing present knowledge, this book contains a great deal of new material.

The fourth chapter, entitled "The Upper Atmosphere Studied from Rockets," is by three authors, and will be of particular interest. In "Research Programmes," J. L. Greenstein discusses general topics and summarizes the preliminary results obtained, with special reference to solar radiation and the solar spectrum; H. E. Clearman deals with "The Ultra-Violet Solar Spectrum," and describes the first experiments with rocket spectrographs, while in the third section E. Durand describes rocket sonde research at the Naval Research Laboratory. Other chapters in the book deal with such subjects as the spectra of night sky and auroræ, atmospheric circulation, the geological evidence on the evolution of the Earth's atmosphere, and the composition and nature of the uppermost air.

Three of the last four chapters are purely astronomical, and again will be of great interest to the members of our Society. It cannot be said that any of our neighbour worlds present inviting atmospheric envelopes. In "Spectroscopic Observations of the Planets at Mount Wilson," T. Dunham concludes that Mercury is virtually airless (a statement that is certainly not likely to be challenged!) while the atmosphere of Venus is composed largely of carbon dioxide, and that Mars suffers from an almost total lack of oxygen, even water vapour being excessively rare there. As for the Moon, Dr. Kuiper ("Surveys of Planetary Atmospheres") says that "it is still a moot question whether or not the Moon possesses a very thin atmosphere," but it is a pity that no reference is made to the fogs and mists observed from time to time on certain parts of the lunar surface, and whose reality cannot possibly be questioned. (Very recently a Russian scientist, Y. N. Lipski, claims to have established the existence of a lunar atmosphere by the twilight polarization method, and even to have measured its density, confirming Pickering's estimate of 1/10,000th of that of the Earth; but just how much faith can be placed in this is not clear at the moment.)

The book is signally free from misprints; the print is good, and the diagrams and illustrations well reproduced. There are also numerous references. Studies of planetary atmospheres are of vital importance in the interplanetary project, and this volume is a positive mine of information. P. A. M.

Rocket Propulsion Elements

(By G. P. Sutton. Chapman and Hall Ltd., 37, Essex Street, W.C.2. 1949. 20s. net. 294 pp., illus.)

As the first attempt in the English language to survey the basic elements and the technical problems of rocket propulsion from the point of view of a practising rocket engineer, this book demands close attention. There can be few, if any, branches of science or technology that have had such a high ratio of popular to technical books as has been the case in rocketry. Although much useful work, for the engineer has been published during the past few years, it has been scattered in so many journals that it is difficult for most engineers to obtain even an outline of the principles and modern practice of the art.

Mr. Sutton is well qualified to write this book. For four years after obtaining his B.S. and M.S. degrees at the California Institute of Technology he lectured at that Institute in mechanical engineering, and later in rocket propulsion at the University of California. During the war he taught war training courses in gas turbines and jet propulsion. He has had six years of industrial rocket experience and since 1946 has been supervisor of Propulsion Development of North American Aviation Inc.—a firm known to our readers as the manufacturers of the rocket projectile NATIV.

The author has placed the emphasis strongly on liquid-propellant motors, relegating solids to one short chapter, which could with advantage be omitted from future editions and the space used to extend the discussion on liquid-propellant motors. He has, of necessity, with such a wide-reaching subject, treated his matter in a broad manner, but has not omitted any essential topic,

dealing with the history, nozzle theory and thermodynamics, propellant choice and performance calculations, motor design, feed systems and testing. The material is well chosen and together with an excellent series of photographs, diagrams, graphs and tables is blended into a most readable and attractive work. Design equations are not derived (this will, perhaps, please many engineers and displease many physicists) but recourse to the references placed at the end of each chapter will enable readers to refer to the relevant theory if they so wish. Two excellent features are the worked examples in the text and the problems at the end of each chapter—although answers to these would be welcome in future editions.

This book can be unreservedly recommended to readers, with some engineering or technical background, who wish to obtain a sound knowledge of the principles and design of liquid-propellant rocket motors. J. H.

ABSTRACTS

EDITED BY J. HUMPHRIES

Rockets and Other Thermal Jets Using Nuclear Energy, with a General Discussion on the Use of Porous Pile Materials

(H. S. Tsien. *M.I.T. Nuclear Science & Engng. Seminars*, LIV and LV, May 13 and 15, 1947, NP-156, 25 pp. Also in *Science & Engng. of Nuclear Power*, Vol. II, pp. 177-95.)

An account of possible use of nuclear energy by heating hydrogen to a temperature of 6,000° R. in a reactor and expanding the gas through a conventional rocket nozzle. The use of porous material is suggested in order to get a large area for heat transfer.

The Design of Tanks for Liquid-Propellant Rocket Power Plants

(C. C. Ross and R. B. Young. *J.A.R.S.*, Sept.–Dec., 1948, No. 75, pp. 107–118, illus., tabs., refs.)

This paper considers the function of tanks in rocket power plants, the operating requirements of the tanks, and the various configurations encountered in conventional rocket power plants. The choice of material is also dealt with.

Influence of Earth's Gravitation on the Requirements of the Vertical Trajectory Rocket with Special Reference to Escape

(J. P. Sellers. *J.A.R.S.* Sept.–Dec., No. 75, pp. 126–142, illus., refs.)

This paper considers the principal differences between the ideal and actual long-range rockets, inasmuch as it accounts for the additional energy required of the actual rocket due to the time for acceleration of such a rocket to escape velocity. A table of correction factors is given which can be used with the ideal rocket equations to give approximate actual rocket results.

La Navigation Interplanetaire

(René Brest, *Science et Vie*, August, 1949, pp. 85–90, tabs., illus.)

Much of this article is devoted to a description of the ideas of the great French pioneer, Robert Esnault-Pelterie. Readers are reminded that he was already studying the problems of astronautics in 1910, and by 1939 had succeeded in building a rocket motor giving 300 kg. thrust for 55 sec., which could have sent a projectile weighing 100 kg. to an altitude of 100 km. He also obtained an exhaust velocity of 2·4 km./sec. from the liquid oxygen/petrol combination.

Latterly, Pelterie has not continued with his researches on chemical rockets but has made a study of the problems of nuclear energy; in May 1947, he lectured before the French Aero Club on its possibilities for interplanetary travel.

The *Science et Vie* article also describes the pioneer work of the American, Goddard, and proceeds to discuss the dynamics of space flight with regard to mass ratios, exhaust velocities, journey times, step rockets ("fusées-gigognes"), etc. The "Viking" rocket is described and illustrated as an example of current achievement, also "un projet conçu par des techniciens anglais," which turns out to be the Smith–Ross man-carrying rocket. A drawing is also reproduced of a possible three-step rocket with a take-off weight of 55 tonnes, to take a 50 kg. payload of instruments to the Moon.

It is suggested that exhaust velocities of 4 to 5 km./sec. may be possible from chemical propellants (oxygen/hydrogen), and as much as 6 to 8 km./sec. from the application of nuclear energy. Eventually, exhaust velocities approaching 10,000 km./sec. may be realisable from some form of electrostatic (ion) rocket using nuclear power; this might make it possible to travel on hyperbolic orbits and greatly reduce transit times.

The author concludes that travel to bodies within the Solar System is by no means a Utopian dream, but believes that interstellar flight must remain in that category unless the physiologists can develop some system of suspended animation to enable the passengers to survive the prohibitively long journey times.

Radio Telemetering: Factors Influencing Choice of System

(G. I. Hinckley, *Electronic Engng.*, June, 1949, Vol. 21, No. 256, pp. 209–211, 223, refs.).

The types of system in current use are briefly reviewed. These are frequency multiplexing, time multiplexing and composites of the two. The choice of system, modulation method and carrier radio frequency are then dealt with, followed by a consideration of the choice of commutation method for time multiplexing. It is concluded that, in general, the simplest method is best and that many requirements of a telemetering system can be met by a time multiplexing system, using one of the forms of mechanical commutator, the output of which is used to frequency modulate a sub-carrier of about 100 Kc/s., the sub-carrier amplitude modulating the main R.F. carrier. This amplitude modulation is arranged to modulate the carrier so that the peak to mean ratio of the

R.F. output is about three to one. Such a system is very flexible and can be designed to handle up to about 50 channels. The simplest possible arrangements will give overall accuracies of around 10 per cent., but with some increase in complexity up to about 2½ per cent. is possible.

Operational Aspects of Guided Missiles

(Lt.-Col. H. B. Hudiburg and Lt.-Col. R. G. Thomas, *Antiaircraft J.*, 1949, Vol. 92, Jan.-Feb., No. 1, pp. 13–17, March–April, No. 2, pp. 31–33, May-June, No. 3, pp. 19–21.)

The first part presents a general background of the guided missile art, including the types of missiles. It is emphasized that the use of these new weapons would introduce many new tactical and logistical problems. In the second part specific types of weapons are considered, namely, anti-aircraft, 0–150 mile range surface-to-surface, 150–500 mile range surface-to-surface, and anti-missile. Their performances and methods of use are discussed. The third part is devoted to methods of training personnel, and weapon supply, transportation and distribution.

Some Observations on the Problems of Rocket-motor Cooling Design

(J. L. B. Selwood, *J.A.R.S.*, March, 1949, No. 76, pp. 16–26, illus., refs.).

A survey of the processes involved in regenerative cooling. Topics dealt with are cooling passage design, forced convective cooling, film boiling cooling, sweat cooling, heat flow through the wall, wall strength and materials selection. Amongst his conclusions the author states that the problems of heat transfer and cooling design in rocket motors can be evaluated by orthodox and simple test methods and that the cooling problems are capable of satisfactory solution.

RECENT AND FORTHCOMING MEETINGS

November 14, 1949 (Monday). "Interplanetary Exploration," by G. V. E. Thompson, to the Royal Liberty School Science Society, Romford, Essex, at 4.10 p.m.

November 18, 1949 (Friday). "Rockets and Space-Flight," by J. Humphries to the Engineering Society, University of Birmingham, Edgbaston, Birmingham 15, at 5.15 p.m.

January 7, 1950 (Saturday). "The Circum-Lunar Rocket," by K. W. Gatland and A. E. Dixon, to the Society at Caxton Hall, Caxton Street, S.W.1, 6 p.m.

January 13, 1950 (Friday). "Rockets and Interplanetary Travel," by J. Humphries, to Brush Apprentices' Association, King's Head Hotel, Loughborough, Leics., 7.30 p.m.

January 14, 1950 (Saturday). "Space-stations," by E. Burgess, to the N.W.D.C. of the Society, at Adult Education Institute, Lower Mosley Street, Manchester 2, Lancs., at 6.30 p.m.

January 27, 1950 (Friday). "Rocket Propulsion and Interplanetary Flight," by A. V. Cleaver, to the Birmingham Branch of the R.Ae.S., at the Birmingham Chamber of Commerce, New Street, Birmingham, at 7.30 p.m.

February 4, 1950 (Saturday). A discussion, "The Effects of Interplanetary Flight," by the Society at Caxton Hall, Caxton Street, S.W.1, at 6 p.m.

February 8, 1950 (Wednesday). "Recent Advances Towards Interplanetary Travel," by G. V. E. Thompson, to Ilford District Branch of the Association of Scientific Workers, at Seven King's Branch Library, High Road, Seven Kings, Essex, at 7.30 p.m.

February 8, 1950 (Wednesday). "Rocket Propulsion and Interplanetary Flight," by A. V. Cleaver, to the Brough Branch of the R.Ae.S., at the Lecture Hall, Electricity Showrooms, Hull, Yorks., at 7.30 p.m.

February 8, 1950 (Wednesday). Visit to an Astronomical Observatory. A visit arranged for members of the N.W.D.C. of the Society. Intending visitors should notify the Branch Secretary as soon as possible as the party is limited: at 8 p.m.

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